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ALTERNATIVE FORCE EVALUATION WITH MULTIPLE ATTRIBUTE UTILITY MODELING.

By

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EXECUTIVE SUMMARY

Introduction

Land combat is a complex phenomenon which requires meticulous and careful preparation if a force is to be successful against an adversary. In an environment of increasing weapon system sophistication, attention to the acquisition process and emphasis on U.S. Army doctrine and tactics in conventional warfare, the force structure decision maker is faced with complicated tradeoffs among competing organizational objectives.

A force analysis methodology is described in this study which:

1. provides a general yet powerful modeling process for any organizational level,

2. provides an evaluation technique for studying force structure alternatives,

3. provides an easily followed audit trail to highlight force alternative deficiencies for any scenario.

4. provides a framework for integrating personal judgments and values into a quantitative evaluation,

5. provides a commonly accepted, easily understood communication device for force planners, and

6. provides input for the planning, programming, and budgeting process by rank ordering force alternatives.

The Procedure

A multiple attribute utility modeling approach is presented. A five step iterative process is used to describe the modeling procedure.

Step 1: Develop a general conceptual understanding of the problem to include the decision environment, the system and its objective(s), the criteria for alternative selection, the available problem solutions, and the associated data.

Step 2: Develop a hierarchical framework of the proper system by specifying the objective(s) decomposed into defining attributes and further broken down into measurable subattributes.

Step 3: Determine the range of consequences an alternative might produce and develop appropriate related utility functions which define the worth of each consequence.

Step 4: Develop a preference structure for the decision maker which indicates the relative importance of the elements in each level of the hierarchy.

Step 5: Evaluate each alternative for comparison using the preference structure and hierarchical model.

The Example

Three alternative U.S. Army battalion task forces in Europe are evaluated with the multiple attribute utility modeling methodology. Force qualities of lethality, survivability, supportability, and manageability form the first level of the task force model. These qualities are decomposed

in a variety of ways to demonstrate the flexibility of the modeling process. A detailed alternative evaluation is performed using the fully developed manageability hierarchy to demonstrate the mathematical technique involved. The audit trail and deficiency highlighting capabilities are presented by example.

Methodology Impact on Management

The methodology presents potential solutions to some of the problems of management. By forming a macro-structure hierarchical model from Department of Defense downward or from battalion upward, and automating the evaluation process, a basis for a force analysis management information system could be evolved. Effective communication from a "common sheet of music," easily incorporated leadership, strategy, tactics, and technology changes, and marginal analysis capabilities for the budgeting process are expected benefits from such an information system.

Conclusions

The following conclusions are drawn about the multiple attribute utility modeling methodology.

1. It is a reasonably simple, yet powerful analysis technique which derives advantages from the hierarchical nature of the model and the employment of utility and preference structures.

2. It is particularly appealing for force analysis problems because of its general modeling ability, leading to possible universal models, and its ability to rank order force alternatives for any given scenario and any decision maker's viewpoint.

3. The methodology provides a potential management information system structure of aggregated models for all organizational levels in the U.S. Army. The resultant analytical capabilities would assist management during all phases of the planning, programming, and budgeting process.

PREFACE

The authors would like to acknowledge the assistance of LTC William Breen and Dr. Gerald Anderson of the Directorate of Battlefield Systems Integration, DARCOM. They gave freely of their time and their insight regarding areas of potential research which gave us essential initial direction. Colonel Anthony G. Pokorney, Director of the Analysis Directorate, DCS for Combat Developments, TRADOC was similarly instrumental in helping us focus our effort. He and his staff patiently shared their expertise as we developed the background for our work. LTC David F. Dianich, USAF, Technical Advisor, Tactical Air Forces Mission Area Planning deserves special recognition as the man who introduced us to the Multiple Attribute Utility Analysis technique. Colonel Gilbert Green, Instructor in the Defense Economics and Decision Making department of the Naval War College was our advisor. His guidance and encouragement was most important and sincerely appreciated. The comments of LTC Paul Goree, NWC Faculty were also very helpful. We appreciate the efforts of Debby Tavares and Chris Anderson of the Center for Advanced Research, Naval War College, who struggled with the onerous job of deciphering the drafts and typing our report.

For all this assistance we are most grateful and certainly share whatever attention the report may receive. They were not, however, consulted at every phase of the report and any errors of commission or omission are those of the authors alone.

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CHAPTER I

INTRODUCTION

Background

Since the end of the Vietnam War, the Army has embarked on a modernization of equipment, training, and doctrine. Dozens of highly sophisticated hardware and software systems are being prepared for integration into our fighting organizations, while managers at all levels struggle to find optimal allocation of the new resources. Literally millions of dollars have been spent on analytical efforts to assist in the decision making process, yet no clear-cut impact assessment paradigm has emerged.

From the lowest combat element to the top echelons of Army command, the decision process has become more and more complicated. Even at the battalion task force level, there are many alternative ways to organize and allocate resources to be ready to fight the next battle. Our best effort is demanded by the public, particularly when other national programs enjoy relatively higher priorities. A close look at how optimal resource allocation can take place for the fighting units is needed to insure that every possible benefit is derived from our investment.

Problem

It would be a simple matter to counter any threat anywhere military forces were required if resources were unconstrained. Since a commander cannot commit all the force he needs to a particular operation, the next best alternative is to plan the employment of his given resources in a manner which maximizes their contribution. Unfortunately, the process of deciding how to utilize the resources is complex and dependent upon uncertain data on the enemy and friendly capabilities, as well as the human judgments and experiences of many people. Further complications arise because of terrain and climate conditions and the turbulence caused by periodic rotation of the leadership. It is obvious that, as combat has become more sophisticated, the pressures on the decision makers at all levels have increased accordingly.

It follows then, that preparatory efforts to combat can be decisive. These preparations must be done well, with all the analytical resources possible exerted to achieve maximum effectiveness. The resultant force analysis, done properly, can serve to reduce some of the complexity and assist in the communication process. The analysis must be consistent from top to bottom, and should be able to stand the scientific tests of validation and replication of results.

The Force Analysis Problem

How many tanks should be employed per platoon for the European scenario? Do presision-guided munitions enhance our capabilities against Soviet armor? Are less sophisticated weapons sufficient? What is the impact of smaller staffs on combat power? With a limited budget, should the U.S. Army procure aircraft or ground weapon systems? These questions and thousands more must be answered by decision makers and analysts if force optimization is to be achieved or even approached.

Consider the general problem of the force analyst depicted in Figure 1. Resource inputs of men, supplies, equipment--all money-constrained--must be aggregated in the best alternative way to produce *combat outputs of enemy personnel* and equipment kills, friendly protection, territorial gains, etc. If the force analyst can use a single objective of combat, such as maximize enemy personnel kills, the task is considerably easier. Unfortunately, consideration of multiple and often conflicting objectives, such as maximize enemy personnel and weapon system kills, minimize friendly personnel kills, minimize terrain loss, etc., ad infinitum is required. The number of these objectives and the degree to which they conflict is highly subjective and a matter for high-level decision.

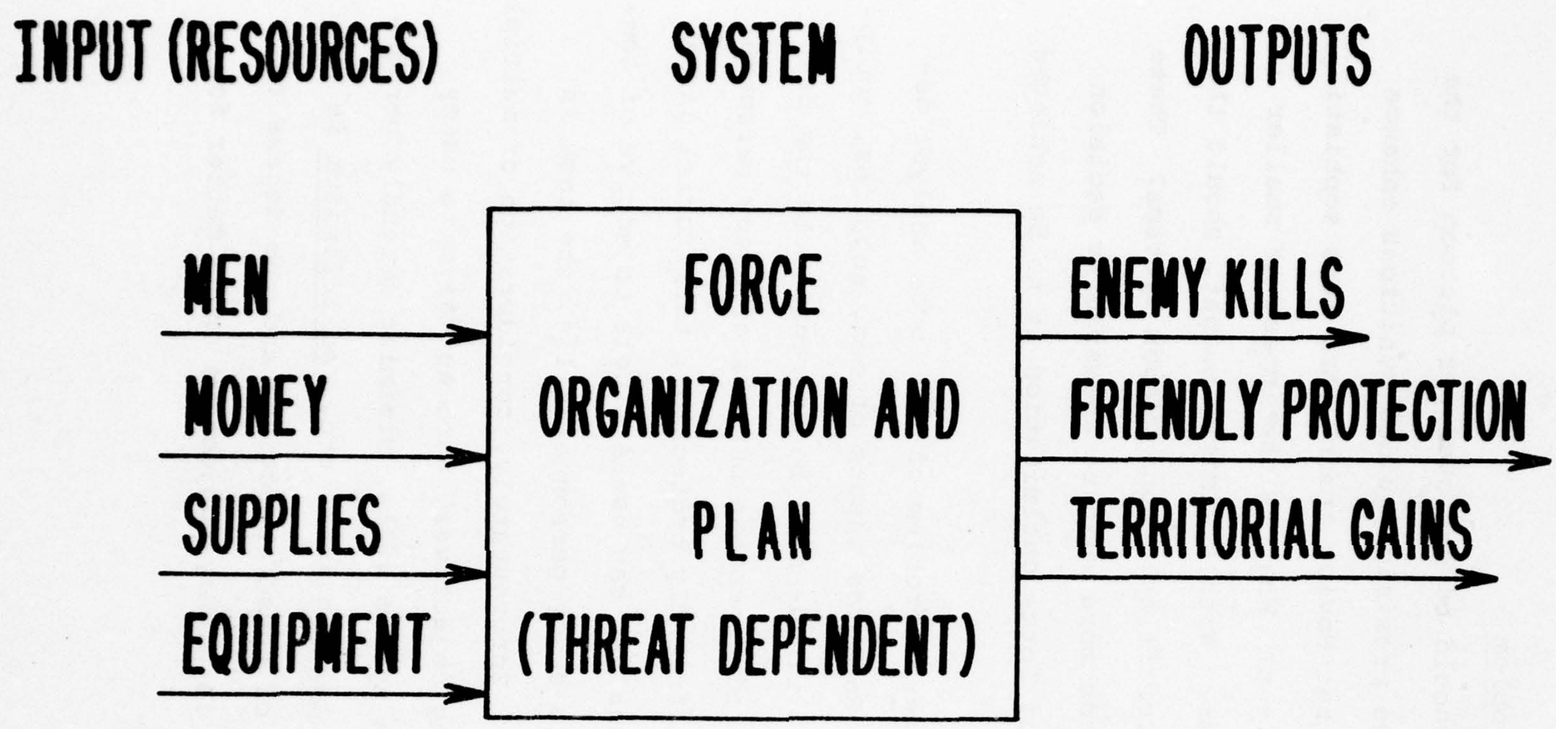


FIGURE 1: INPUT-OUTPUT MODEL

The crux of force analysis is deciding which of a set of alternative structures is best for a specific scenario, i.e., threat and environment, according to a prescribed list of objectives.

A technique that is flexible enough to allow both objective and subjective evaluations of alternative force structures regardless of the criteria would be a powerful tool. Further, if the technique provided a systematic and prescriptive approach to decision making, it should be used. And finally, if the methodology assisted in the processes of communication and advocacy or reconciliation, it would provide even greater benefits.

Objectives

A force analysis methodology is needed that:

1. provides a sufficiently general, yet analytically powerful process to allow modeling of forces at any level, from platoon to Department of Defense;

2. provides a technique for comparing, on general terms, alternative plans and organizations of weapons and support system mixes for a given environment;

3. highlights combat and support deficiencies for the given environment and provides an analytical audit trail for determining the location of the deficiencies;

4. provides a framework for the integration of personal values and judgments with the more objective analytical results from the research community;

5. provides a commonly accepted discussion model for describing combat which can assist in removing troublesome abstract concepts by defining them in contexts the layman can understand; and

6. demonstrates a potential for prioritizing research and development, operations analysis, and procurement programs based upon their individual contributions to combat power.

Purpose

This study is intended to propose a general purpose methodology which U.S. Army force planners at any level can use for determining the best alternative plan and organization for combat under constrained resources. The approach chosen to meet the study objectives is described in sufficient detail by this report that it can be used as a guide by analysts faced with force-structuring problems. In explanation of the approach, a force analysis model outline at the battalion task force level is presented.

Scope

The approach described in this study is based upon elements of multiple attribute utility theory from the field of decision analysis. As such, the technique appears to be

unlimited in its use for multiple objective decision problems. For the force analysis application, MAU modeling theoretically allows <u>any</u> size force to be analyzed for <u>any</u> scenario based upon the judgments of <u>any</u> person or group of persons. The approach provides significant analytical power, limited only by the imagination of a decision maker or analyst.

The study is organized into five chapters and one appendix. Chapter I has been an introduction to the problem and objectives of this study. Chapter II discusses the general theory and techniques of mutiple attribute utility modeling. In Chapter III, specific techniques used in modeling a battalion task force are provided, along with alternative evaluation example calculations. Chapter IV describes the potential use of MAU force analysis from a management perspective and suggests how the technique might be used to form the basis of a mangement information system. Conclusions derived from the study effort are provided in Chapter V. Appendix I presents the basics of the underlying mathematical theory.

CHAPTER II

FORCE ANALYSIS WITH MULTIPLE ATTRIBUTE UTILITY MODELING

Introduction

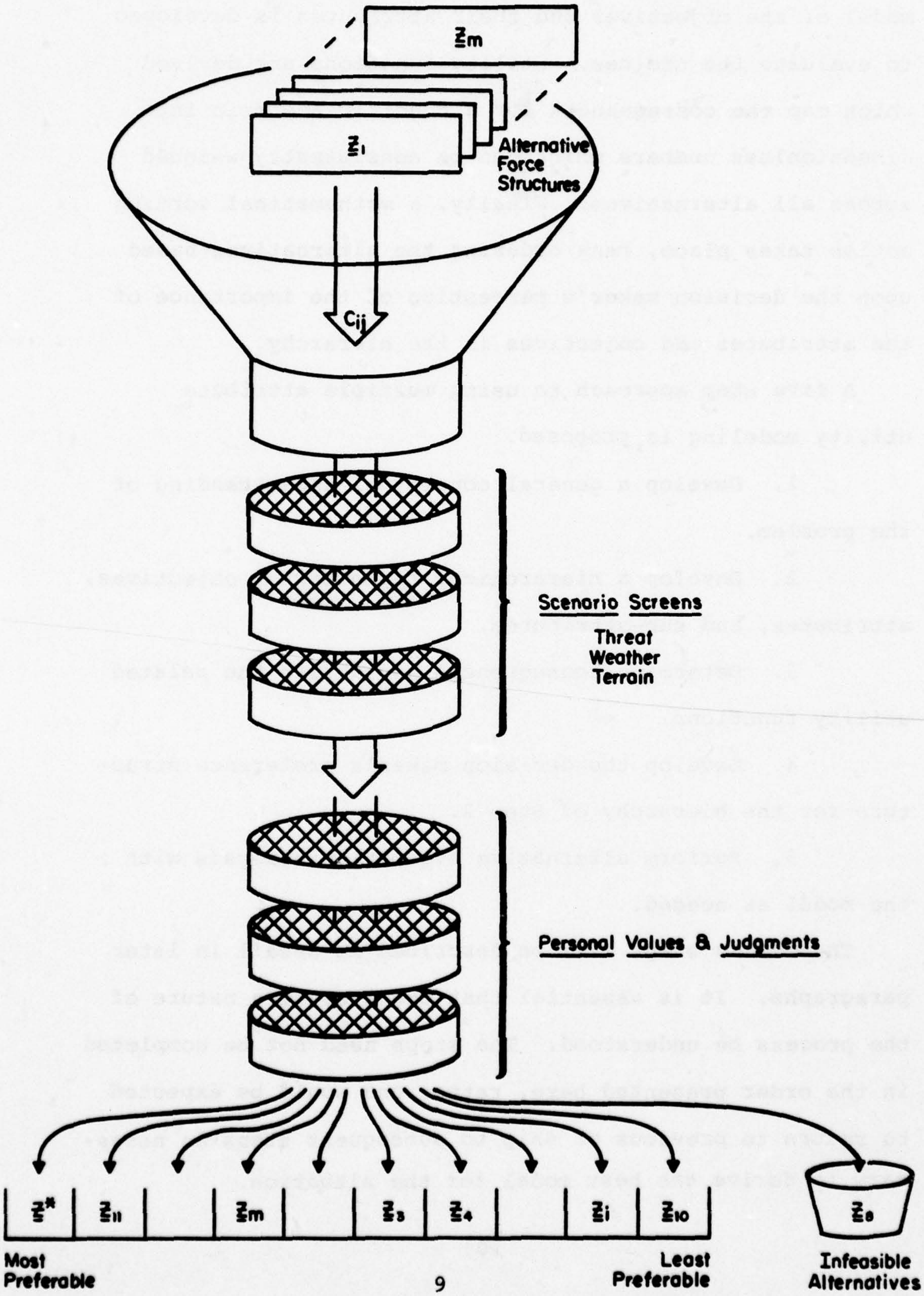
Force analysis for every branch of military service is a continual process. New doctrines of warfare emerge, scientific contributions provide new weapons, and changing socio-political conditions produce new threats and decrease old. How well the United States structures its forces for all services will be the key to winning, losing, or deterring future wars.

As alluded to earlier, the process of force structuring is extremely complex. Resources are constrained, friendly and enemy capabilities are fraught with uncertainty and decision makers are faced with literally millions of decisions without adequate analytical tools. Multiple attribute utility modeling techniques provide promise for dealing effectively with some of this complexity.

The Multiple Attribute Utility Modeling Process

The concept of evaluating alternative force structures with MAU modeling is pictorially represented in Figure 2. Force alternatives are generated for the problem to be analyzed and data on the consequences (resultant effects of choosing an alternative) are collected. A hierarchical

FIGURE 2
MULTIPLE ATTRIBUTE UTILITY EVALUATION



model of the objectives and their attributes is developed to evaluate the choices. Utility functions are derived which map the consequences for a specific scenario into dimensionless numbers which can be consistently weighed across all alternatives. Finally, a mathematical sorting action takes place, rank ordering the alternatives based upon the decision maker's perception of the importance of the attributes and objectives in the hierarchy.

A five step approach to using multiple attribute utility modeling is proposed.

1. Develop a general conceptual understanding of the problem.

2. Develop a hierarchical framework of objectives, attributes, and sub-attributes.

3. Determine consequences and derive the related utility functions.

4. Develop the decision maker's preference structure for the hierarchy of Step 2.

5. Perform alternative evaluation analysis with the model as needed.

These five steps will be described in detail in later paragraphs. It is essential that the iterative nature of the process be understood. The steps need not be completed in the order presented here, rather one would be expected to return to previous or skip to subsequent steps as necessary to derive the best model for the situation.

Step 1: Conceptual Understanding

One could say that this is a much too obvious step and is unnecessary for discussion of MAU modeling. To the contrary this step is perhaps the most important for it encompasses many tasks for the analyst.

Many procedural paradigms exist in the literature of praxeology--the science of making decisions. One such process with which the authors are comfortable is taught at the Naval War College, Newport, Rhode Island.[1] It is a seven phase process of formulation, search, evaluation, interpretation, decision, verification, and implementation. The MAU conceptual understanding step requires all actions covered in Phases I and II, formulation and search respectively. The formulation phase covers several basic elements:

1. A decision situation which presents a decision maker with a choice among alternatives to solve a problem.

2. A basic understanding of the system in question, its definition and relationship with other higher and lower systems.

3. A statement of the system objective which is consistent with higher level objectives.

4. An identification of key factors which bound and define the analysis to be conducted.

5. A specification of measure(s) of effectiveness and measure(s) of cost, i.e., consequences of choosing a particular alternative.

6. A criterion chosen to relate measures of effectiveness and cost and used to rank the alternatives, and

7. A set of assumptions/estimates which are used to treat the uncertainty of the variables and constraints in the problem.

The search phase is the creative and time-consuming portion of the process, requiring:

1. Generation of a set of alternatives which can achieve the system objective, and

2. Collection of data relevant to the alternatives generated.

If during this conceptual step, it is determined that a single objective can be optimized, then analysis techniques other than multiple attribute utility modeling may be appropriate. Conversely, if a single objective cannot be selected from among multiple conflicting objectives, MAU modeling is an attractive process.

Edwards and Guttentag point out that the number of multiple objectives specifies the dimensions of the problem.[2] For example, one of many dimensions of the force analysis problem could be--reduction of friendly casualties. The number of relevant dimensions should be kept as small as realistically possible, preferably between eight and fifteen. Usually recombination, omission or restatement of the objectives keeps the number of dimensions manageable.

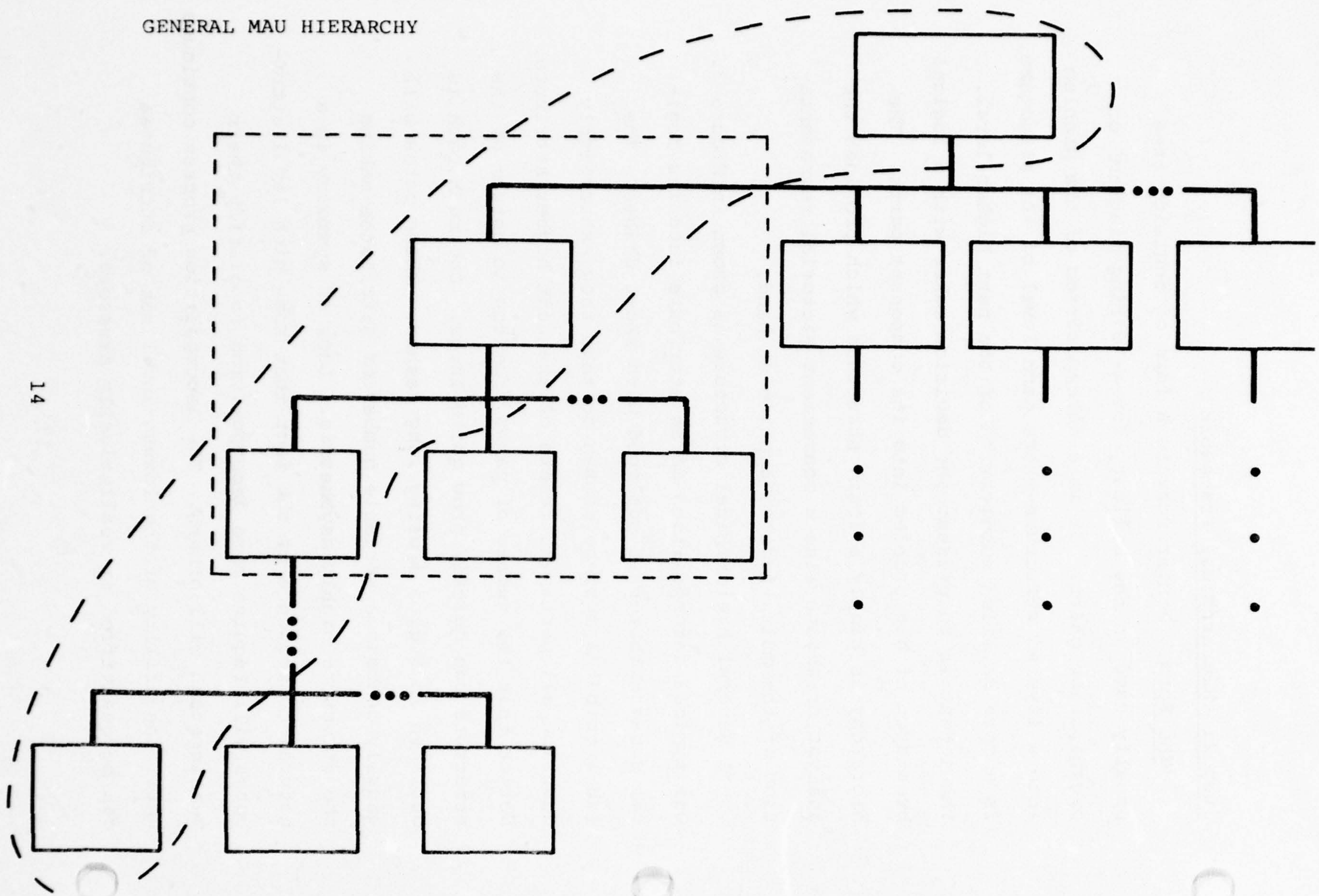
Step 2: Hierarchical Framework

The Form. A hierarchy is a form of decision tree usually used in the military for a "wiring diagram" or organization chart. It is a decomposition of the problem into a layered structure where each level of the structure is a more detailed subdivision of the next higher level. The intent is to present the decision maker with a logical breakdown of his problem into its component parts. The hierarchy is simply a logic structure which provides the analyst or anyone else a convenient pictorial representation of the multi-faceted problem at hand.

A general hierarchical structure is shown in Figure 3. One typical decomposition of an attribute into its logical sub-attributes is outlined with short dashes. The sub-attributes must be chosen so that they exhaustively describe all pertinent facets of the next higher attribute. Notice that the number of paths from top to bottom of the structure can quickly grow quite large. One such path is outlined in Figure 3 using long dashes. These paths will usually contain a variable number of attributes making the structure highly asymmetric. Lack of symmetry is a natural consequence of the fact that some high level attributes will require more decomposition to clarify their meaning than will others. The decomposition process continues until the utility of the lowest level set of attributes can be quantified or realistically assessed.

FIGURE 3

GENERAL MAU HIERARCHY



Hierarchy Construction. A MAU hierarchy is different from the organization chart. The user of this technique is urged not to attempt modeling along organizational lines but rather to use organizational objectives. One can approach hierarchy construction in many ways, e.g., from all encompassing objectives down or lowest level force characteristics up, etc. In all circumstances it will become quickly apparent that a tree of this kind is always only a piece of a larger hierarchy, a suboptimization, and must be bounded in some logical manner consistent with the problem being studied. The best guidance is to construct the hierarchy in a manner comfortable to the decision maker, always keeping in mind the problem to be solved.

There are several techniques for decomposing objectives into sub-objectives and attributes and further decomposing the attributes into sub-attributes. The decomposition technique serves to define the concept or quality the objective relates. For example, the artillery like to "move, shoot, and communicate" to be effective in combat. Essentially, there are then three objectives or qualities/concepts which the force must be able to accomplish. How is each defined? Breaking down "move" into its attributes of reaction time, speed, march direction, etc. serves to define the concept of an artillery force moving. Definitions can be obtained from experts, surveys, study of artillery related literature or brainstorming. It is

assumed in the MAU modeling process that most, if not all, of the pertinent objectives, even if conflicting, can be described and judged on an importance basis.

Rules for Hierarchy Construction:

1. At each level, the "test of importance," as suggested by Ellis, should be used.[3] Each attribute or objective is deleted one by one. If alternative selection is unaffected, then that deleted attribute or objective should be excluded, as it is not important. Obviously, one should not delete any one of the objectives "move, shoot, communicate," as they all stand the test.

2. On the other hand, a "test of completeness" should be exercised at each hierarchical level. The set of attributes at a level is complete if a clear understanding of the scope of the next higher level objective is obtained. For example, does "move, shoot, communicate" completely define the effectiveness of an artillery force? What about resupply? Or is resupply an attribute of "shoot?" The answer to these questions are essential in constructing comprehensive and realistic hierarchical models for force analysis. One caution is appropriate. The number of paths proliferate rapidly since each objective begets attributes which beget sub-attributes, etc. The number of utility curves required is a function of the attributes and hierarchy levels. Be complete at each level, but be concise.

3. The final rule to follow in hierarchy construction is to seek attributes which are independent. Major difficulties in the evaluation process can be avoided if the sub-elements which describe an attribute or objective are chosen such that they are mutually preferentially independent.[4] Mutual preferential independence is achieved when sub-elements are chosen such that the tradeoffs between any two of them, when all others remain fixed, are independent of the level at which the others are fixed. Referring again to the attributes outlined with short dashes in Figure 3, we would select the lower level attributes such that they are mutually preferentially independent, leading to a full definition of the important aspects of the higher attribute.

Step 3: Utility Functions

The decomposition of the complex problem into its constitutive objectives and attributes continues until the utility of the sub-attributes at the lowest level can be conveniently assessed. The key to the analytical power of evaluation of alternatives with MAU modeling lies in the specification of worth described by these utilities at the end of each hierarchical path. An alternative determines a set of consequences which have now been modeled as sub-attributes. For example, a reaction time of one hour would be a single consequence of a specific alternative. Of what worth is it to the decision maker that the force can react in one hour? A properly constructed utility function specifies the worth, over the range of values expected for reaction

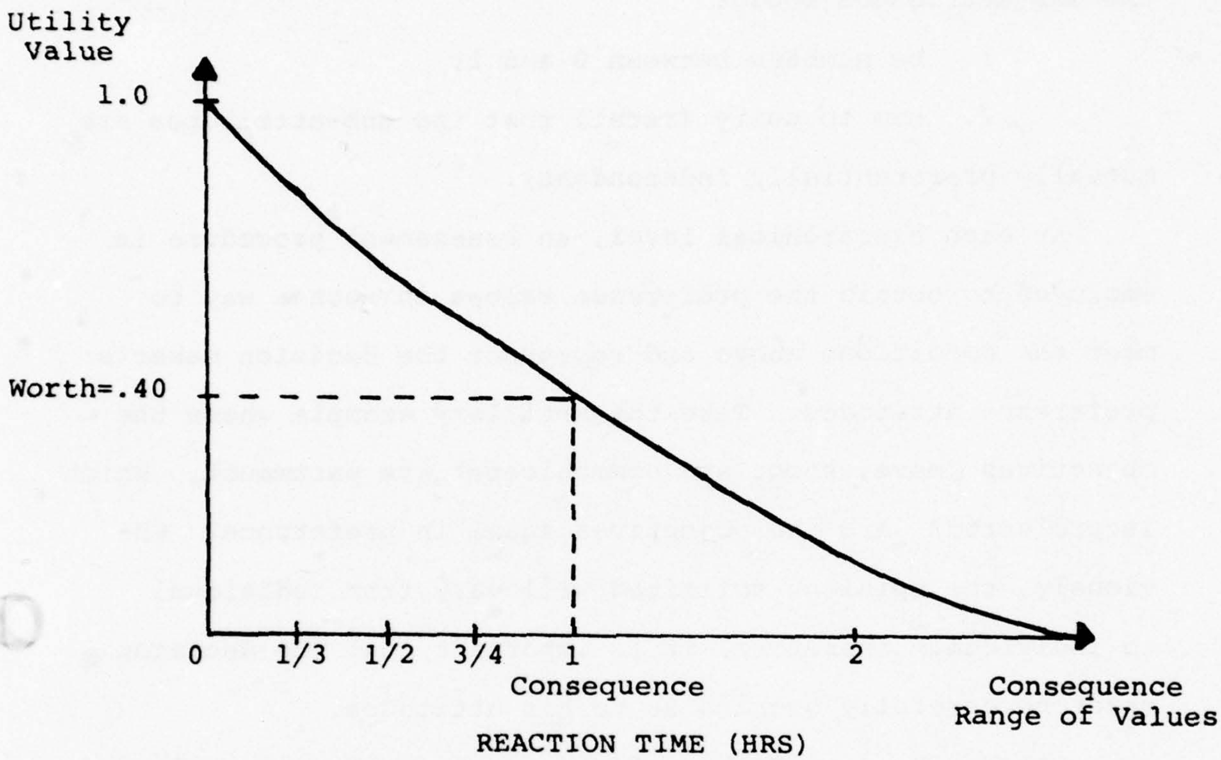
time or any other sub-attribute in the model. The utility curve for reaction time may appear as shown in Figure 4. Thus, the utility function maps a consequence into a worth or utility value.

Establishing realistic utility functions is an art which depends heavily on the judgment and common sense of the analyst. Experts should be consulted whenever possible to establish the range of values each consequence can be expected to take on, now and in the future. The curve shape can be established by careful questioning procedures, such as the Delphi technique, used to elicit the feelings of worth from the decision maker.[5] Implications of utility curve shapes are discussed in Appendix I.

The analyst will discover that not all consequences can be assessed quantitatively. Some subjective or direct preference consequences will have to be assessed. An example in force analysis is the commander's confidence in his staff. The recommended technique is to have the decision maker directly set the worth as he sees fit for the alternative being evaluated. Whenever possible, objective measurements are preferred, but an advantage of multiple attribute utility modeling is its power to assess <u>all</u> facets of an alternative.

FIGURE 4

HYPOTHETICAL UTILITY FUNCTION FOR ARTILLERY FORCE REACTION TIME FOR MOVEMENT



Step 4: Preference Structure

At this point the analyst should feel comfortable with the problem, particularly if several iterations have taken place in building the hierarchy from the original problem. A well structured hierarchical model specifying objectives, attributes, and sub-attributes with appropriate utility functions has been derived which defines the worth of the consequences produced by each of the alternatives.

The judgment of the decision maker can be incorporated by assigning a preference value which measures the importance of each sub-attribute in describing the next higher level

attribute. The preference values are similar to probabilities in many respects. If we refer again to the section of Figure 3 outlined in short dashes, the preference value for the sub-attributes would:

1. be numbers between 0 and 1;

2. sum to unity (recall that the sub-attributes are mutually preferentially independent).

At each hierarchical level, an assessment procedure is employed to obtain the preference values in such a way to meet the conditions above and represent the decision maker's preference attitudes. Take the artillery example where the objectives "move, shoot and communicate" are paramount. Which is preferred? Are the objectives equal in preference? Obviously, the opinions solicited will vary from individual to individual; therefore, it is important that the decision maker be carefully queried as to <u>his</u> attitudes.

Let X_1, X_2, and X_3 be defined as the preference values for move, shoot, and communicate, respectively. The analyst can begin by asking the decision maker to consider all three objectives at their lowest value, then which one he prefers to move all the way to its maximum contribution first (say, shoot). In effect, he has said that $X_2 > X_1$ and X_3. After further questioning, the analyst might infer that the decision maker's preference structure is $X_2 > X_3 > X_1$, but this is not the whole story.[6] Quantitatively, how much does he prefer his artillery force to be able to shoot, communicate and move?

It may be convenient to allocate 100 points among the three objectives, e.g., $X_2 = 60$, $X_3 = 30$, $X_1 = 10$, and then convert these to decimals. If this is too confining, <u>any</u> number of points N can be used to represent the preference magnitudes, e.g., $X_2 = 40$, $X_3 = 30$, $X_1 = 25$. By normalizing, the appropriate preference values can be found as $X_2 = .42$, $X_3 = .32$, $X_1 = .26$.

Once preference values for each level in the hierarchy are elicited, the model for a specific decision maker is complete. The final step is to use the model to evaluate the alternatives under study.

<u>Step 5: Alternative Evaluation</u>

The numerical technique (see Appendix I) of alternative evaluation is analogous to the process of "folding-back" decision trees in decision analysis. The consequences of each alternative are converted by the utility functions into worth ratings. These "payoffs" at each tree tip are multiplied by the corresponding preference values and summed at the nodes or branching points. In turn, these values are multiplied by the preference values at the next hierarchical level and summed, etc. until the entire hierarchy has been processed. The evaluation procedure results in a single number between 0.0 and 1.0. This rating is a <u>relative</u> measure of the preference for one alternative over another. For force analysis, the authors prefer to call it a combat power potential index (CPPI).

Once all alternatives are evaluated the single numbers obtained provide a systematic, comprehensive ranking of the alternatives based upon the decision maker's own preference attitudes. Further analysis can be conducted as necessary. For example, the decision maker can easily have the analyst retrace the source of greater worth of one alternative over another. For complicated hierarchies this audit trail capability is extremely valuable yet simple to apply. See Chapter III for a detailed example. It is also a simple matter to array all contributions of the alternative consequences to the CPPI in a matrix for comparison to other alternatives. The use of matrix formats for management is discussed in Chapter IV.

Summary

The five step multiple attribute utility modeling process has been discussed in detail. To perform alternative force evaluation with this tool is systematic and comprehensive, yet uncomplicated. It is a powerful analytical technique which when properly employed can identify force deficiencies and requirements and their contribution to an index of worth which is consistent and representative of a particular preference structure. Multiple attribute utility modeling may be the super-structure needed to consolidate force analysis efforts and prioritize new analytical efforts.

CHAPTER III

MULTIPLE ATTRIBUTE UTILITY MODEL OF A U.S. ARMY BATTALION TASK FORCE

Introduction

The purpose of this chapter is to provide a hypothetical, but realistic, example of the MAU technique described in Chapter II using the battalion task force as a vehicle. The battalion task force model is only presented in sufficient detail to make the techniques understood. A model for actual use would be developed much more extensively.

The reader should understand that use of a MAU model as described herein provides a "snapshot" of the combat power potential of a military unit at a specific point in time evaluated for a particular threat and terrain condition. Evaluation of alternatives for task force organization or resource allocation is only concerned with making good decisions prior to combat. MAU modeling is not intended to assess the chance outcomes of a dynamic battlefield fraught with uncertainty. The procedure relies on advantageous combat outcomes stemming from good decisions and proper preparation.

Approach

The current land combat doctrine in Europe is oriented toward fighting a "central battle" with a Warsaw Pact force usually at a battalion or battalion task force organization level. It is this battle which is the point of concentration

of resource allocation priority and command interest in the face of numerically superior opposing forces. The importance of this organizational level makes it appropriate as an example of the MAU modeling process. The remainder of this chapter describes the action taken during each of the five steps of the process.

Conceptual Understanding

The conceptual understanding description for the formulation phase is provided below.

1. Decision Situation. The 1st of the 51st Armor Task Force, composed of three armor companies, one mechanized infantry company, and one 155 mm self-propelled artillery battery has been assigned a new defensive position. The task force commander must determine the best way to defend his area with the resources available. Since all resource allocation decisions are not final, the staff is in a position to recommend such preferences as ammunition type to be used, blocking positions, additional support, etc.

2. System. The task force consisting of all elements of 1/51 Armor minus Company D, Company C 2/53 Mechanized Infantry attached, and Battery B 2/23 Artillery in direct support, constitute the system of interest. The task force operates under the control of 3d Brigade, 25th Armored Division.

3. System Objective. The objective is to defend in sector while inflicting maximum casualties on the enemy.

4. Key Factors. Some of the key factors are:

a. Terrain

b. Threat

c. Time available

d. Friendly forces and missions

5. Measures of Effectiveness and Measure of Cost.

a. Measures of Effectiveness: The measures of effectiveness (MOE) are the utility values generated from the lowest level consequences. For example, for the staff evaluation there are four MOEs--number of staff members, average number of years in the unit, average number of years on a staff and commander's confidence rating. The MAU process synthesizes these and all the other MOE into a single Combat Power Potential Index (CPPI) for the task force.

b. Measures of Cost: Costs are assumed constant since the commander is allocating a fixed set of resources in various ways to develop alternatives.

6. Criterion. The best alternative is the one which maximizes CPPI for a constant cost.

7. Assumptions.

a. The battalion task force commander has a fixed set of resources to allocate.

b. The commander is familiar with the terrain he must operate upon and the major enemy weapon systems he will face.

c. The commander is familiar enough with his unit and personnel to be able to assign reasonable utilities and make subjective judgments where required.

The search phase requires generation of alternative force organizations and employments for the task force. Three alternatives are described in Table 1. Appropriate data are tabulated for the manageability objective sub-attributes only, in the interest of clarity. The data provided have been manipulated into the form needed for MAU model alternative evaluation. Corresponding utility values are also tabulated.

Hierarchical Framework

The hierarchy model for the battalion task force is depicted in Figures 5-12. For this case (Figure 5, p. 28), the qualities of lethality, survivability, supportability, and manageability surfaced as a set of objectives which one would like to see maximized. Certainly, a force should have all the qualities to be successful so this level meets the "test of importance." Whether the model is complete at this level is not as simple. In an early modeling attempt, the authors wanted to include mobility as another force quality. Obviously, a force must be mobile and surely mobility should be maximized. It was reasoned that to be exhaustive, mobility should be included. Unfortunately, mobility is not independent of any of the other qualities even on a preferential basis since lethality is enhanced if a force can move, tanks are less vulnerable if they can maneuver, casualties can be evacuated and saved more readily if air ambulances are available, etc. The solution to this dilemma of independence versus

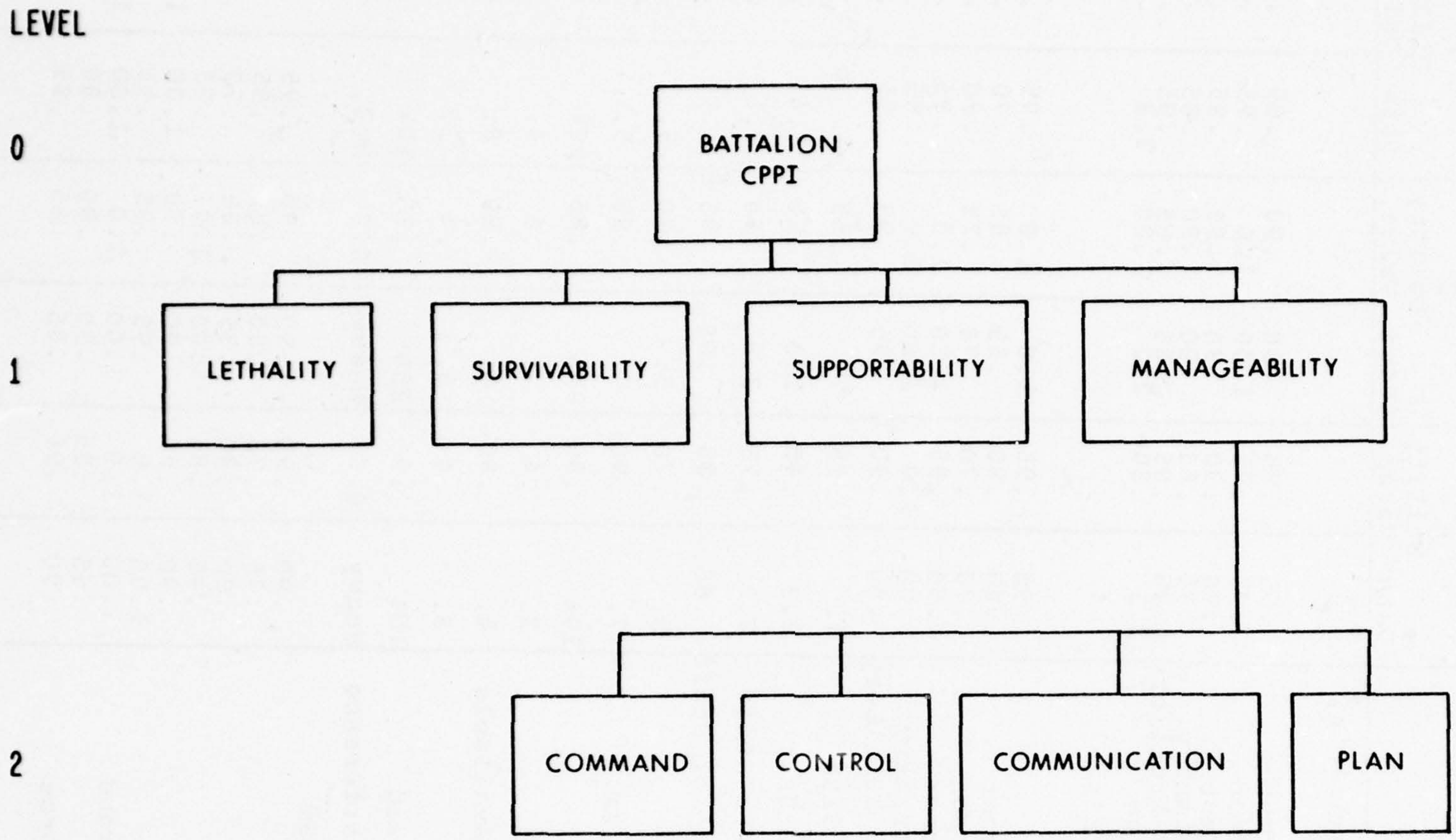
TABLE 1

ALTERNATIVE DATA AND UTILITY VALUES

MANAGEABILITY ATTRIBUTE	ALTERNATIVE A		ALTERNATIVE B		ALTERNATIVE C	
	Data	Utility Value	Data	Utility Value	Data	Utility Value
Subordinate Commander's Rating						
Co. A 1/51 Armor	.95	.95	.90	.90	.95	.95
Co. B 1/51 Armor	.95	.95	1.00	1.0	.95	.95
Co. C 1/51 Armor	.90	.90	.90	.90	.95	.95
Co. C 2/53 Infantry	.85	.85	.90	.90	.85	.85
Battery B 2/23 Artillery	.95	.95	.85	.85	.95	.95
Command Experience	2.2	.80	2.2	.80	2.2	.80
Command Successor's Rating						
Battalion XO	.95	.95	1.0	1.0	.95	.95
Co. A 1/51 Armor	.80	.80	.85	.85	.70	.70
Co. B 1/51 Armor	.70	.70	.75	.75	.80	.80
Co. C 1/51 Armor	.95	.95	1.00	1.0	.95	.95
Co. C 2/52 Infantry	1.00	1.0	1.00	1.0	.95	.95
Battery B 2/23 Artillery	.90	.90	.95	.95	.95	.95
Principal Staff Size	4.	.95	7.	.55	5.	1.0
Average Years in Unit	1.3	.45	1.5	.60	1.4	.50
Average Years on a Staff	2.3	.75	3.5	.90	3.1	.85
Confidence Rating of Staff	.85	.85	.95	.95	.90	.90
Span of Control	5.	.70	5.	.70	5.	.70
Width of Front (km)	7.	.90	7.	.90	5.	.95
SOP Coverage	90%	.90	85%	.85	90%	.90
Links to Higher	3.	.4	4.	.6	4.	.6
FM Frequencies Available	8.	.80	8.	.80	8.	.80
Links to Lower	3.	.4	3.	.4	3.	.4
Hard Copy Required	10%	.9	25%	.75	10%	.90
Expected EW Interference	Heavy	0.0	Heavy	0.0	Mod.	.5
Principles of War						
Mass	.90	.90	.90	.90	.95	.95
Offensive	.75	.75	.80	.80	.95	.95
Surprise	.90	.90	.85	.85	.70	.70
Security	.95	.95	1.00	1.0	.95	.95
Manuever	.90	.90	.90	.90	1.00	1.0
Objective	1.00	1.0	.95	.95	.95	.95
Unity of Command	1.00	1.0	1.00	1.0	1.00	1.0
Simplicity	.95	.95	.90	.90	.80	.80
Economy of Force	.90	.90	.85	.85	.85	.85

FIGURE 5

BATTALION TASK FORCE HIERARCHY OVERVIEW



completeness can be solved by modeling the attributes of each quality in a way to assess the contributions of mobility. The formation of utility functions for lethality and survivability illustrate how this was done for this example (Figures 6 & 7). The mobility problem of modeling also illustrates the iterative nature of the MAU process.

The qualities at the highest level were decomposed into a set of concepts which give meaning to each of the rather nebulous objectives. The pictorial models demonstrate the results. These models are illustrative only and are intended to present a variety of ways of considering qualities which are difficult to define. A short discussion of each of the qualities follows to illuminate different decomposition ideas.

Lethality (Figure 6, p. 30). The quality is decomposed into those weapon systems in a given set of resources which can inflict casualties on the enemy. Each system has different capabilities which are dependent upon the target it is opposing, the terrain on which it is operating, the environment, and the expected enemy employment.

Survivability (Figure 7, p. 31). For this quality, decomposition is based upon the environment and terrain. The threat is considered on the basis of the question "What can kill us?" This exhaustive list of enemy weapon systems is further decomposed to observe effectiveness against friendly targets and expected employment.

FIGURE 6

HIERARCHY MODEL FOR LETHALITY

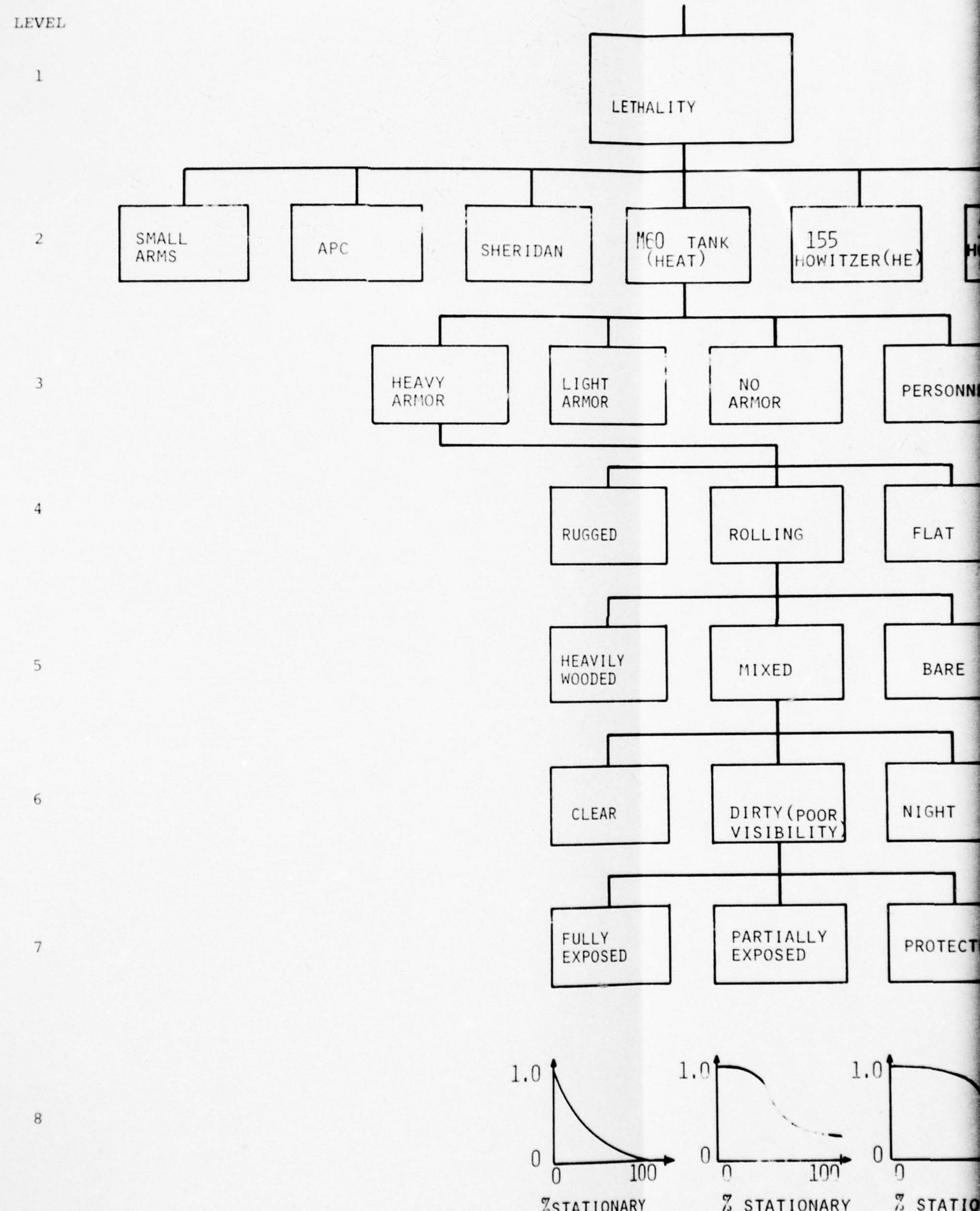


FIGURE 6

HIERARCHY MODEL FOR LETHALITY

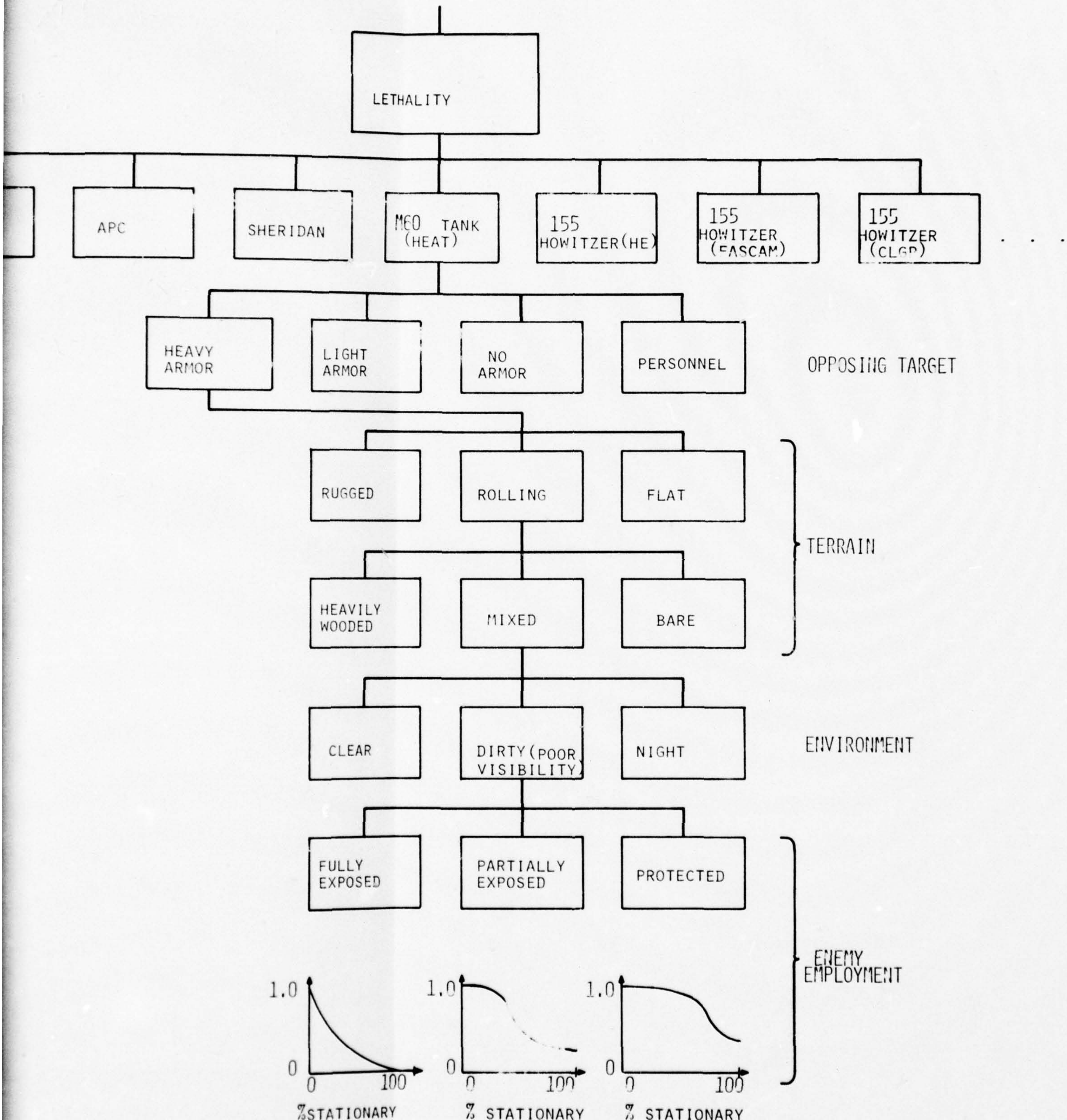


FIGURE 7 - HIERARCHY MODEL FOR SURVIVABILITY

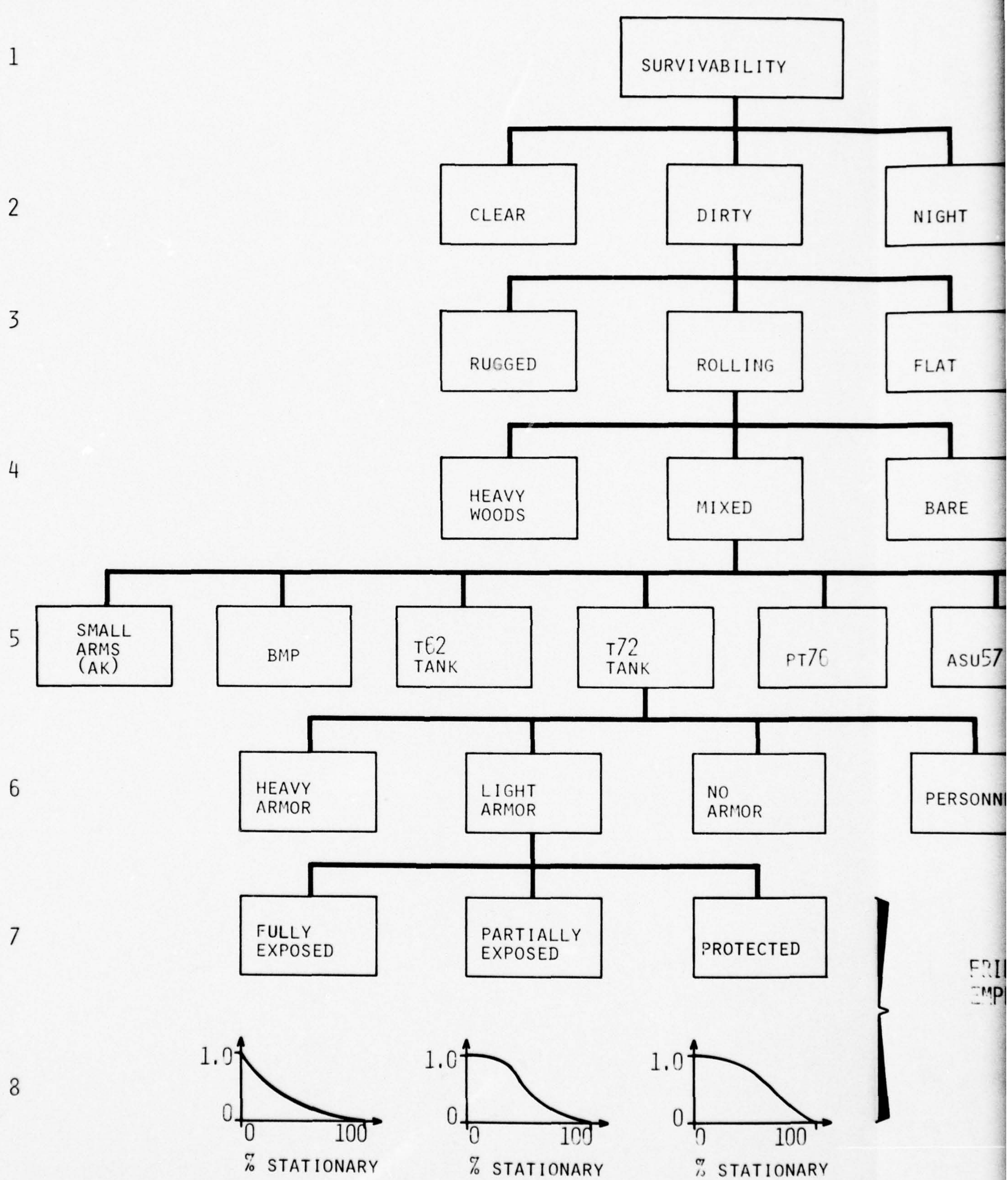
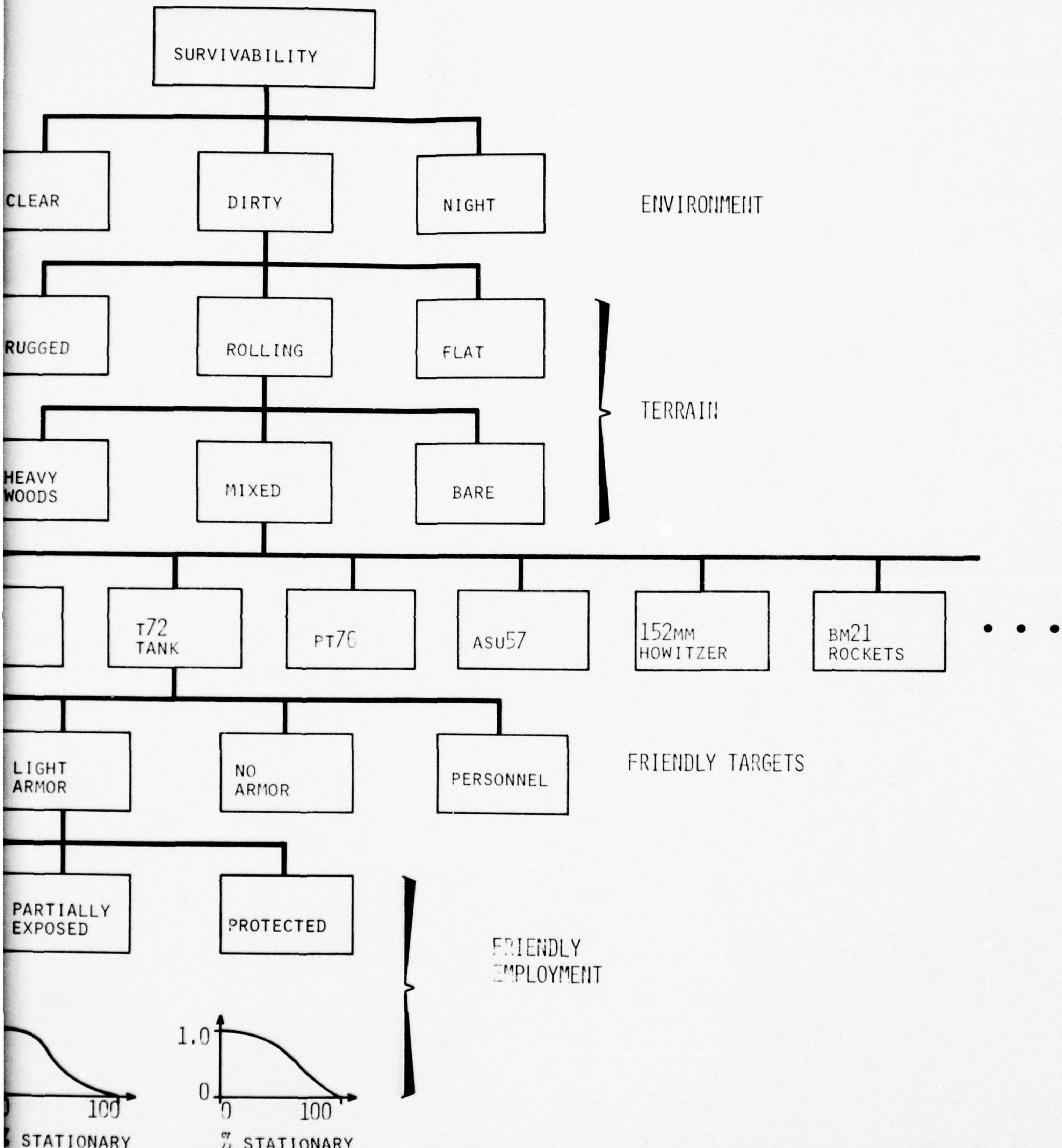


FIGURE 7 - HIERARCHY MODEL FOR SURVIVABILITY



2

Supportability (Figure 8, p. 33). This quality demonstrates the use of current literature to enumerate the functions of support for combat materiel and men respectively.[1] Further decomposition of these functions was made such that quantitative and independent measurement of support capabilities could be assessed.

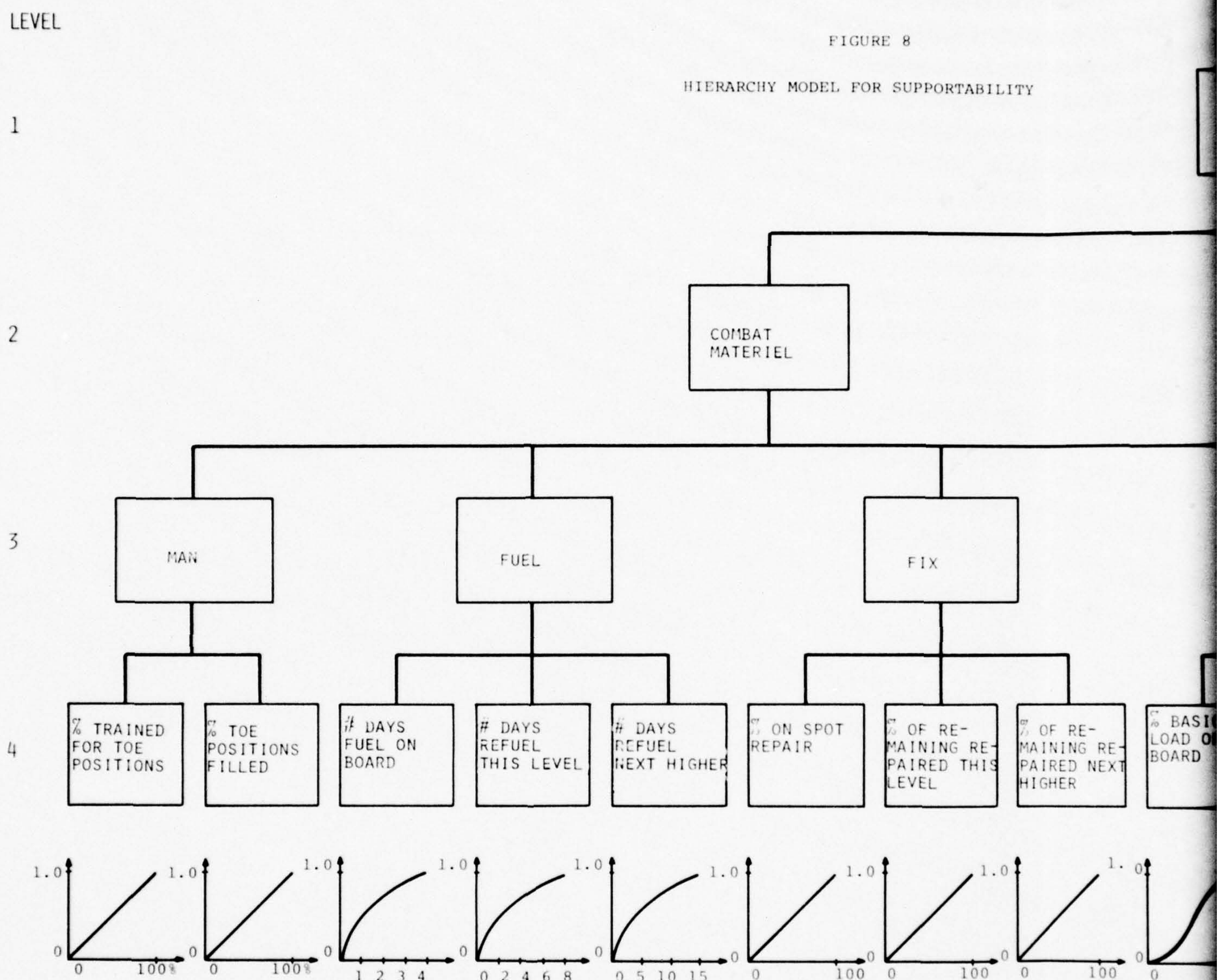
Manageability (Figures 9-12, pp. 34-37). This quality model shows how creative decomposition can be useful in describing an abstract and difficult concept. The first level is conventional wisdom and admittedly may not be complete. Regardless, the combat management functions were decomposed to illustrate how quantitative and qualitative (direct preference ratings)[2] manageability measurements of alternative organizations and plans can be obtained.

It is obvious that the hierarchy of objectives and attributes can be arranged in many ways. The arrangement, that is which level comes first, etc., is not particularly important since the number of paths through the tree remain constant. Conversely, if a level can be eliminated, combined with another level, or reduced in attribute number then the number of paths can be reduced.

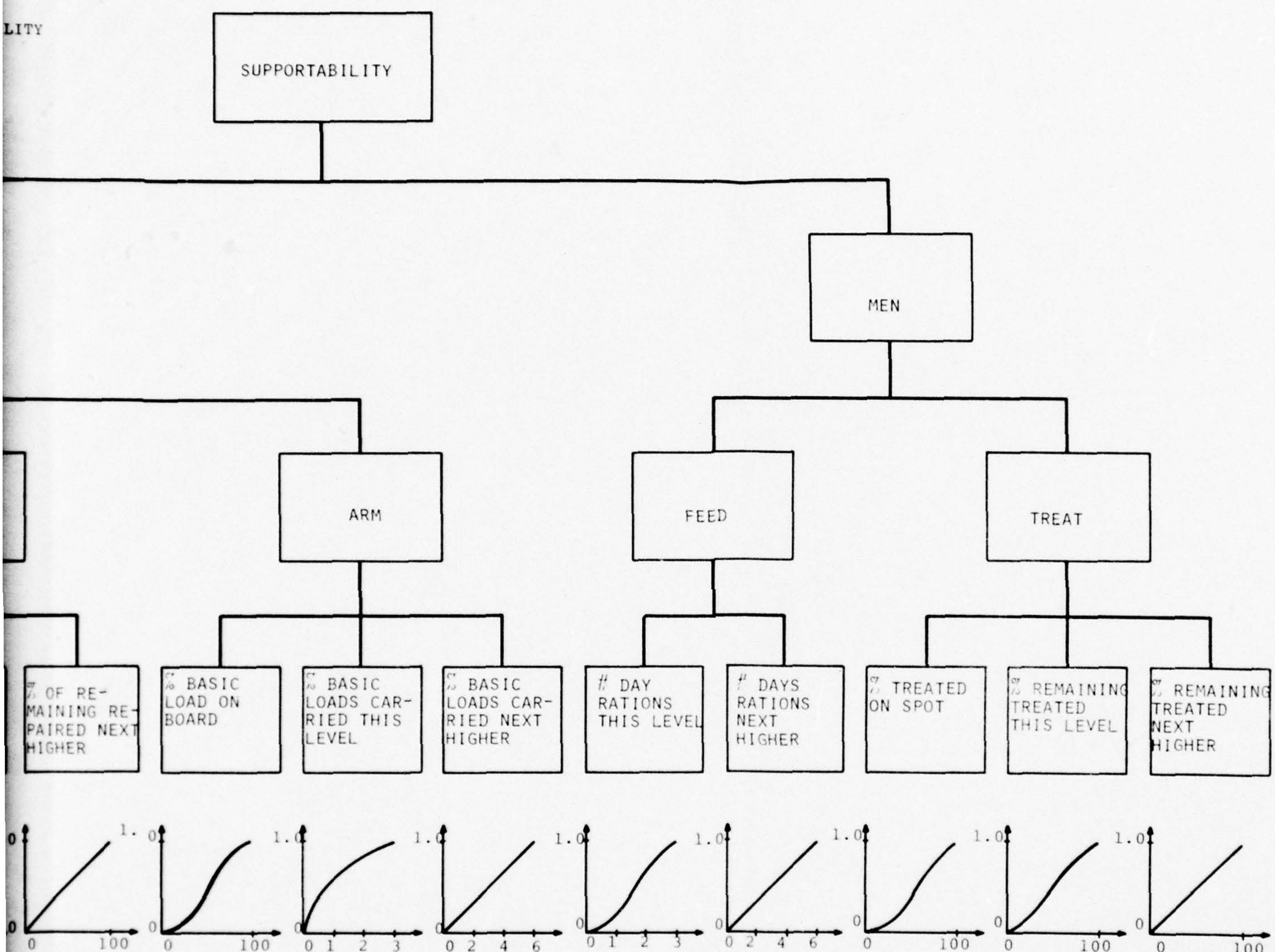
The development of good hierarchical models of the concepts involved is partly art and partly science. In the authors' experience the process becomes easier each time it is attempted. Perhaps a universal model can be derived by experts such that this step can greatly be simplified.

FIGURE 8

HIERARCHY MODEL FOR SUPPORTABILITY



LITY



SUPPORTABILITY
MEN
ARM
FEED
TREAT
% OF REMAINING REPAIRED NEXT HIGHER
% BASIC LOAD ON BOARD
% BASIC LOADS CARRIED THIS LEVEL
% BASIC LOADS CARRIED NEXT HIGHER
# DAY RATIONS THIS LEVEL
# DAYS RATIONS NEXT HIGHER
% TREATED ON SPOT
% REMAINING TREATED THIS LEVEL
% REMAINING TREATED NEXT HIGHER
1.0
0
0 100
0 1 2 3
0 2 4 6

2

FIGURE 9

HIERARCHY MODEL OF COMMAND ATTRIBUTE FOR MANAGEABILITY

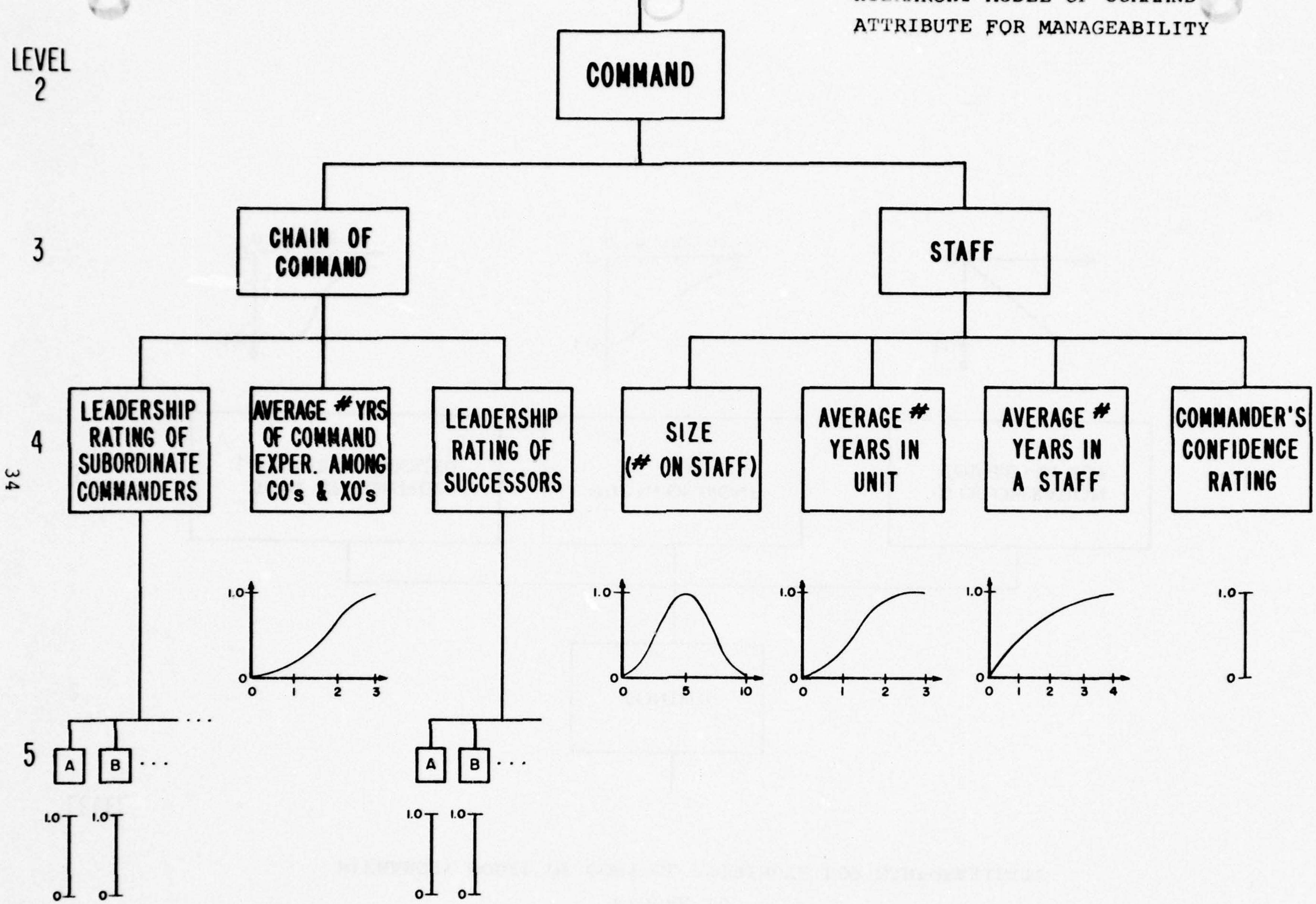
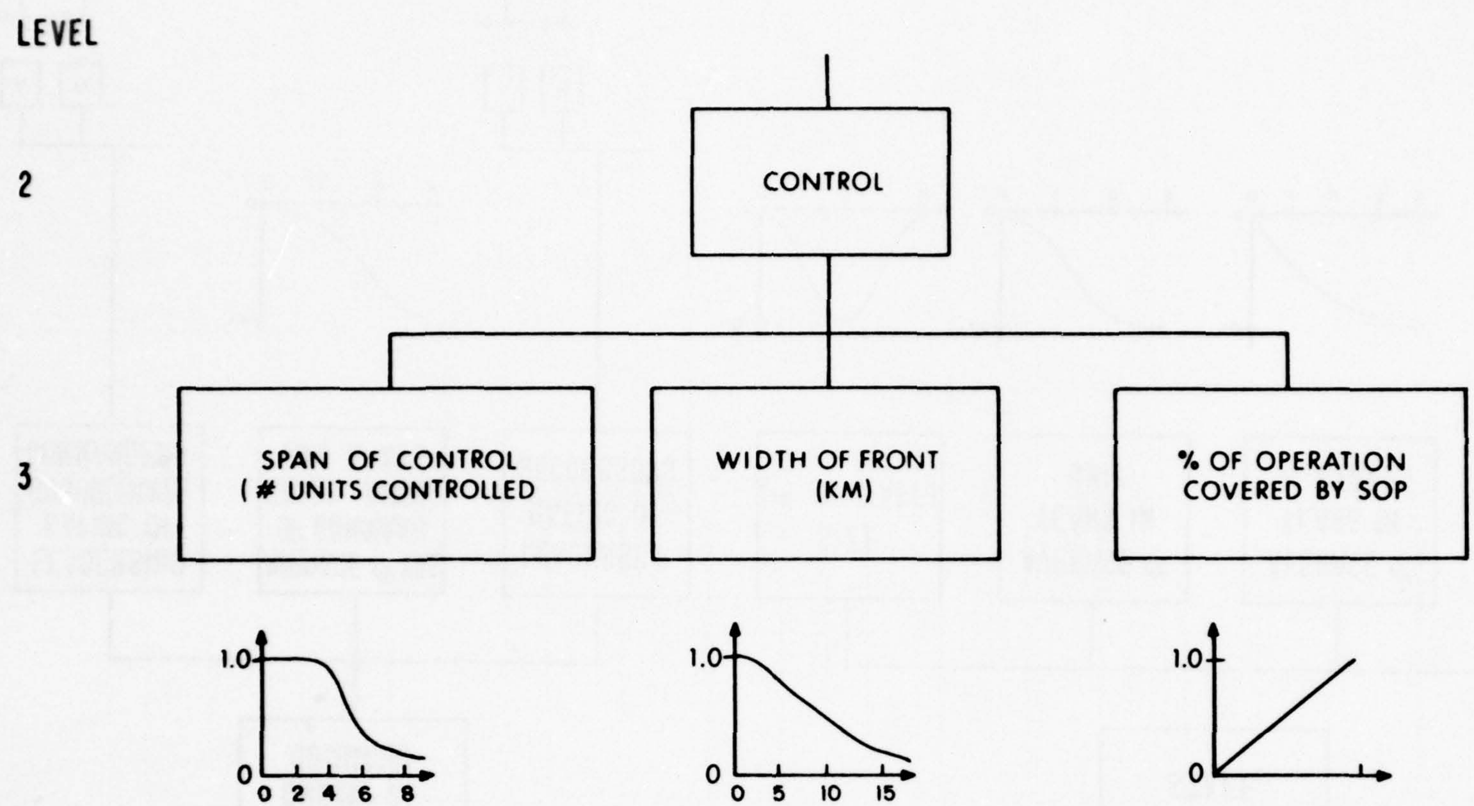


FIGURE 10

HIERARCHY MODEL OF CONTROL ATTRIBUTE FOR MANAGEABILITY



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HIERARCHY MODEL OF COMMUNICATION ATTRIBUTE FOR MANAGEABILITY

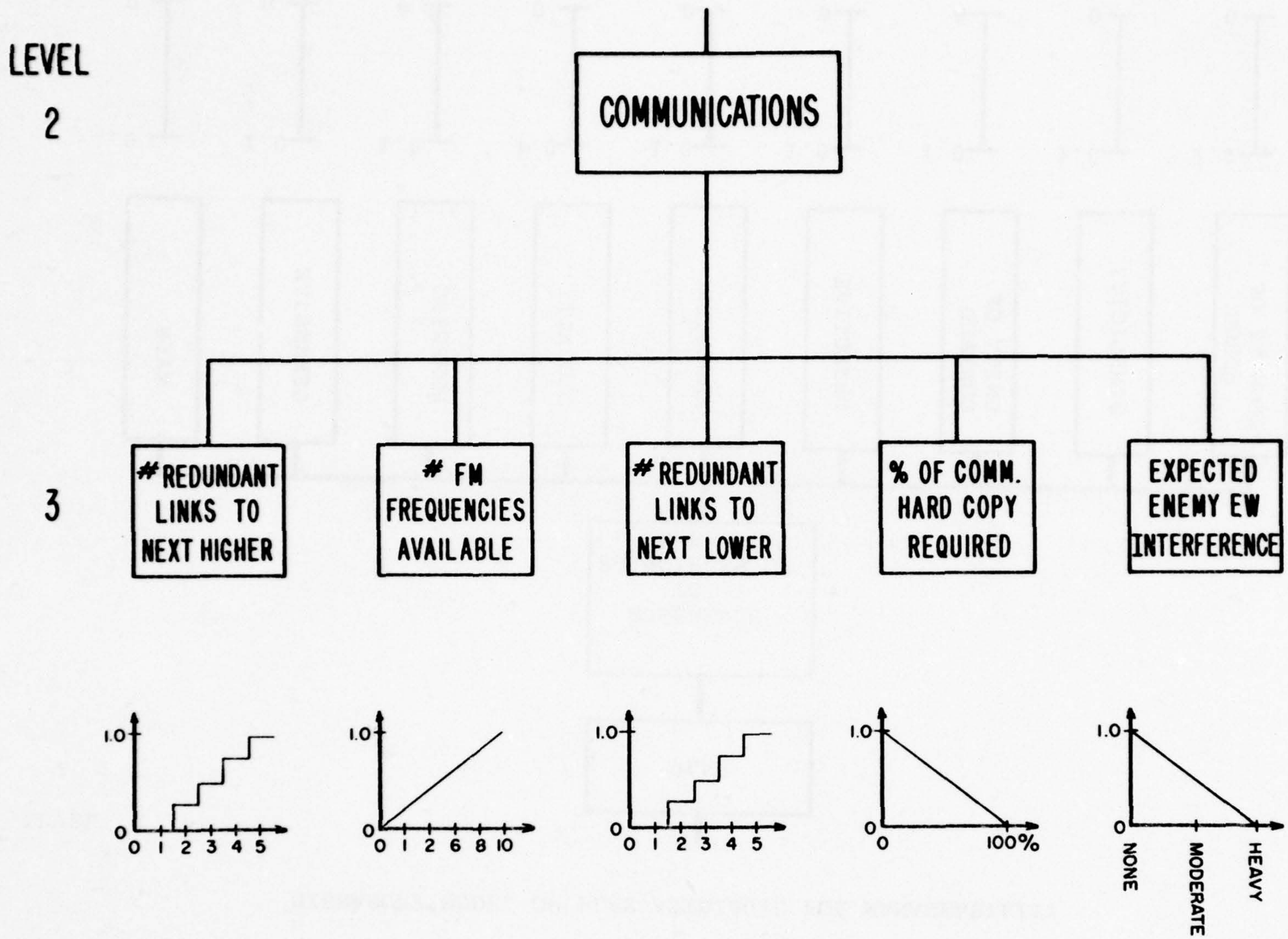
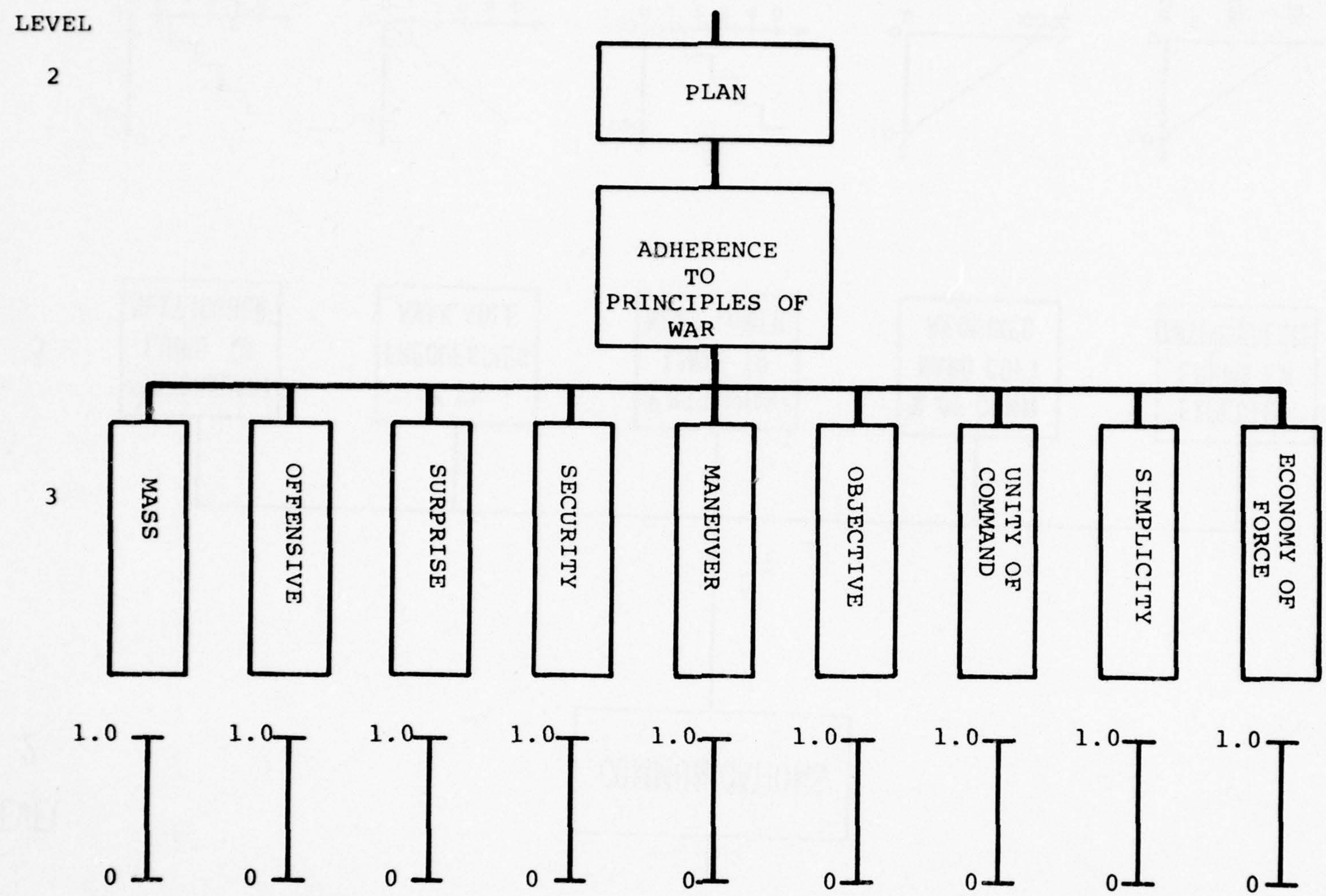


FIGURE 12

HIERARCHY MODEL OF PLAN ATTRIBUTE FOR MANAGEABILITY



Utility Functions. The utility functions depicted in the hierarchy models are hypothetical but shaped realistically. No real data were used for this example, but the relationships shown by the functions are based upon the military experience and judgment of the authors. These functions are intended to be illustrative only.

The utility functions' purpose is to convert a given consequence data item related to an alternative into an evaluation number between 0.0 and 1.0. For example, the size of the battalion task force staff utility function is reproduced in Figure 13. Four, seven, and five principal staff members are required for alternatives A, B, and C respectively. Evaluation numbers are read from the figure as follows:

Alternative	Utility Value (U_{ij})
A	.95
B	.55
C	1.0

Staff size is an interesting example because it illustrates increasing marginal utility up to five members and decreasing marginal utility as the size continues to increase but efficiency begins to suffer.

In a similar fashion to staff size the analyst can obtain the entire set of utility values for all the alternatives. The utility values for the manageability quality are tabulated in Table 1 (page 27).

UTILITY FUNCTION FOR STAFF SIZE

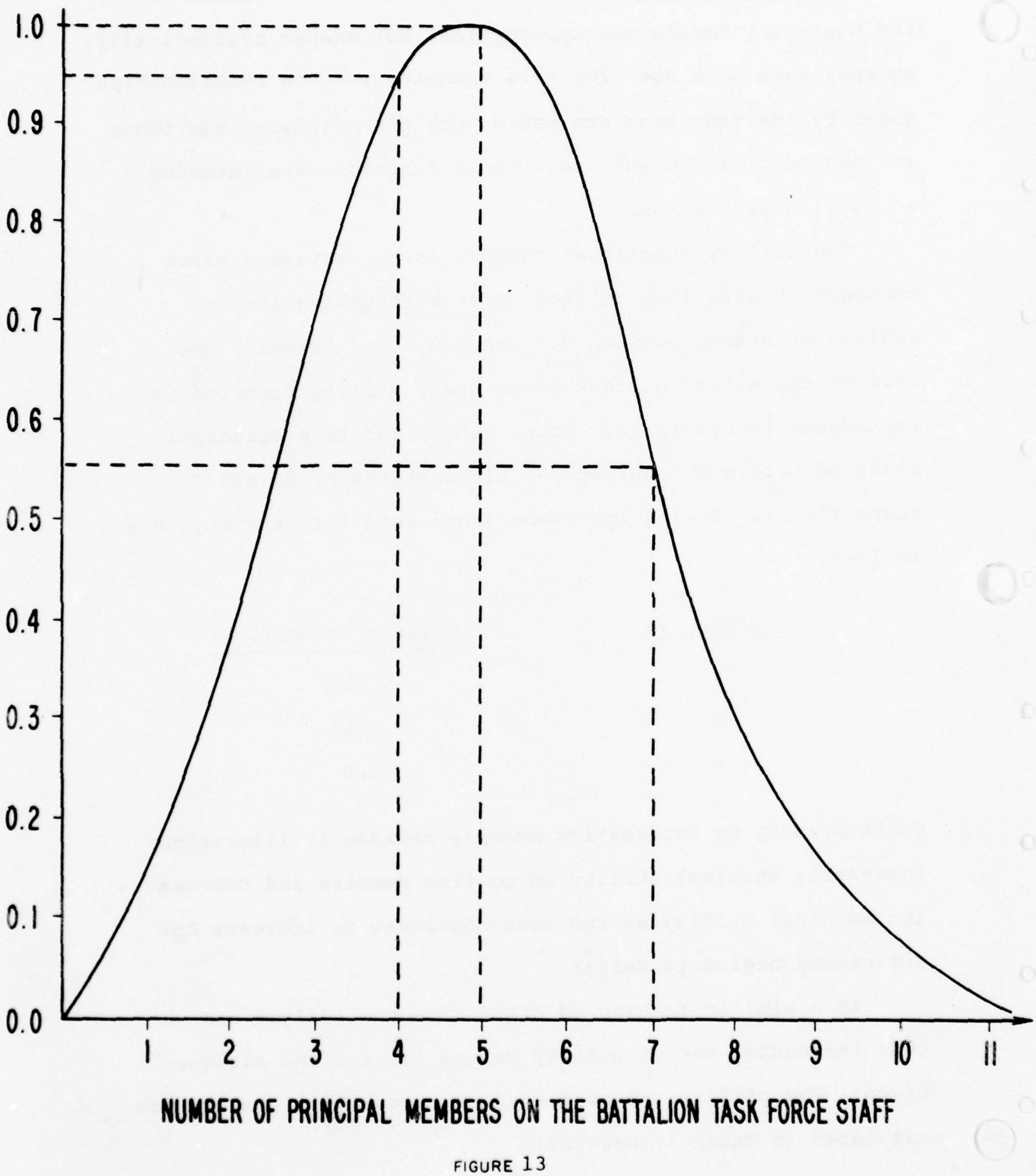


FIGURE 13

Preference Structure. The analyst uses the hierarchy models to elicit a preference structure for the decision-maker involved with choosing among alternatives. The preference structure, as seen by the decision maker, for the manageability objective might appear as shown in Table 2. Note that at each hierarchical level branching point the sum of the preference values is 1.0. At this point in the analysis, the model is complete and alternative evaluation can proceed.

Alternative Evaluation. Only the strictly numerical procedure of "folding back" remains to be done. Tables 3, 4, and 5 show the detailed calculations made for Alternatives A, B, and C respectively for the entire tree using hypothetical numbers for lethality, survivability, and supportability at the top level. It is simply a summation of the products of utility values and preference values at each level.

The single number obtained for each alternative is the combat power potential index (CPPI). This index allows the alternatives to be compared directly since they have been evaluated for the same scenario and with the same preference structure. The alternative with a CPPI closest to 1.0 is the best of the three. For this example, Alternative B should be selected. If this does not correspond to the intuitive selection of the decision-maker, further analysis can be done.

TABLE 2

PREFERENCE VALUES FOR MANAGEABILITY

ATTRIBUTE	LEVEL*	PREFERENCE VALUE
Command	2	.40
Chain of Command	3	.70
Leadership Rating Commanders	4	.60
Co. A 1/51 Armor	5	.20
Co. B 1/51 Armor	5	.20
Co. C 1/51 Armor	5	.20
Co. C 2/53 Infantry	5	.20
Battery B 2/23 Artillery	5	.20
Average Command Years	4	.10
Leadership Rating Successors	4	.30
Bn. XO	5	.25
Co. A 1/51 Armor	5	.15
Co. B 1/51 Armor	5	.15
Co. C 1/51 Armor	5	.15
Co. C 2/53 Infantry	5	.15
Battery B 2/23 Artillery	5	.15
Staff	3	.30
Size	4	.2
Average Unit Years	4	.2
Average Staff Years	4	.2
Confidence Rating	4	.4
Control	2	.30
Span of Control	3	.4
Width of Front	3	.4
SOP Coverage	3	.2
Communication	2	.20
Redundant Links Higher	3	.30
FM Frequencies	3	.10
Redundant Links Lower	3	.10
Hard Copy Requirement	3	.20
EW Interference	3	.30
Plan	2	.10
Mass	3	.05
Offensive	3	.10
Surprise	3	.00
Security	3	.05
Maneuver	3	.20
Objective	3	.25
Unity of Command	3	.15
Simplicity	3	.10
Economy of Force	3	.10

*Refer to Figures 5 and 9-12.

TABLE 3 -- EVALUATION OF ALTERNATIV

	LEVEL 5	LEVEL 4	LEVEL 3	
Manageability				
Command				.86
Chain of Command			.899 x .70 = .6293	
Leadership Rating Commanders		.92 x .60 = .552		
Co. A 1/51 Armor	.95 x .20 = .19			
Co. B 1/51 Armor	.95 x .20 = .19			
Co. C 1/51 Armor	.90 x .20 = .18			
Co. C 2/53 Infantry	.85 x .20 = .17			
Battery B 2/23 Artillery	.95 x .20 = .19			
Average Command Years		.80 x .10 = .080		
Leadership Rating Successors		.89 x .30 = .267		
Bn. XO	.95 x .25 = .2375			
Co. A 1/51 Armor	.80 x .15 = .12			
Co. B 1/51 Armor	.70 x .15 = .105			
Co. C 1/51 Armor	.95 x .15 = .1425			
Co. C 2/53 Infantry	1.00 x .15 = .15			
Battery B 2/23 Artillery	.90 x .15 = .135			
Staff			.77 x .30 = .231	
Size		.95 x .20 = .19		
Average Unit Years		.45 x .20 = .09		
Average Staff Years		.75 x .20 = .15		
Confidence Rating		.85 x .20 = .34		
Control				.82
Span of Control			.70 x .40 = .28	
Width of Front			.90 x .40 = .36	
SOP Coverage			.90 x .20 = .18	
Communication				.42
Redundant Links Higher			.40 x .30 = .12	
FM Frequencies			.80 x .10 = .08	
Redundant Links Lower			.40 x .10 = .04	
Hard Copy Requirement			.90 x .20 = .18	
EW Interference			0.0 x .30 = 0.0	
Plan				.94
Mass			.90 x .10 = .09	
Offensive			.75 x .05 = .0375	
Surprise			.90 x .00 = .00	
Security			.95 x .05 = .0475	
Maneuver			.90 x .20 = .18	
Objective			1.0 x .25 = .25	
Unity of Command			1.0 x .15 = .15	
Simplicity			.95 x .10 = .095	
Economy of Force			.90 x .10 = .09	
Lethality				
Survivability				
Supportability				

TABLE 3 -- EVALUATION OF ALTERNATIVE A

5	LEVEL 4	LEVEL 3	LEVEL 2	LEVEL 1	LEVEL 0
				$\boxed{.76812}$ x .20 = .153624	
			.8603 x .40 = .34412		
		.899 x .70 = .6293			
	.92 x .60 = .552				
20 = .19					
20 = .19					
20 = .18					
20 = .17					
20 = .19					
	.80 x .10 = .080				
	.89 x .30 = .267				
25 = .2375					
15 = .12					
15 = .105					
15 = .1425					
15 = .15					
15 = .135					
		.77 x .30 = .231			
	.95 x .20 = .19				
	.45 x .20 = .09				CPPI .819689
	.75 x .20 = .15				
	.85 x .20 = .34				
			.82 x .30 = .246		
		.70 x .40 = .28			
		.90 x .40 = .36			
		.90 x .20 = .18			
			$\boxed{.42}$ x .20 = .084		
		$\boxed{.40}$ x .30 = .12			
		.80 x .10 = .08			
		$\boxed{.40}$ x .10 = .04			
		.90 x .20 = .18			
		$\boxed{0.0}$ x .30 = 0.0			
			.94 x .10 = .094		
		.90 x .10 = .09			
		.75 x .05 = .0375			
		.90 x .00 = .00			
		.95 x .05 = .0475			
		.90 x .20 = .18			
		1.0 x .25 = .25			
		1.0 x .15 = .15			
		.95 x .10 = .095			
		.90 x .10 = .09			
				.95324 x .30 = .255972	
				.79613 x .40 = .318452	
				.91641 x .10 = .091641	

2

TABLE 4 -- EVALUATION OF ALTERNATIVE B

	LEVEL 5	LEVEL 4	LEVEL 3
Manageability			
Command			
Chain of Command			.91775 x .70 = .642425
Leadership Rating Commanders		.93 x .60 = .558	
Co. A 1/51 Armor	.90 x .20 = .18		
Co. B 1/51 Armor	1.0 x .20 = .20		
Co. C 1/51 Armor	.90 x .20 = .18		
Co. C 2/53 Infantry	.90 x .20 = .18		
Battery B 2/23 Artillery	.95 x .20 = .19		
Average Command Years		.80 x .10 = .08	
Leadership Rating Successors		.9325 x .30 = .27975	
Bn. XO	1.0 x .25 = .25		
Co. A 1/51 Armor	.85 x .15 = .1275		
Co. B 1/51 Armor	.75 x .15 = .1125		
Co. C 1/51 Armor	1.0 x .15 = .15		
Co. C 2/53 Infantry	1.0 x .15 = .15		
Battery B 2/23 Artillery	.95 x .15 = .1425		.79 x .30 = .237
Staff		.55 x .20 = .11	
Size		.60 x .20 = .12	
Average Unit Years		.90 x .20 = .18	
Average Staff Years		.95 x .40 = .38	
Confidence Rating			
Control			.70 x .40 = .28
Span of Control			.90 x .40 = .36
Width of Front			.85 x .20 = .19
SOP Coverage			
Communication			.60 x .30 = .18
Redundant Links Higher			.80 x .10 = .08
FM Frequencies			.40 x .10 = .04
Redundant Links Lower			.75 x .20 = .15
Hard Copy Requirement			0.0 x .30 = 0
EW Interference			
Plan			.90 x .10 = .09
Mass			.80 x .05 = .04
Offensive			.85 x .00 = .00
Surprise			1.0 x .05 = .05
Security			.90 x .20 = .18
Maneuver			.95 x .25 = .19
Objective			1.0 x .15 = .15
Unity of Command			.90 x .10 = .09
Simplicity			.85 x .10 = .085
Economy of Force			
Lethality			
Survivability			
Supportability			

TABLE 4 -- EVALUATION OF ALTERNATIVE B

LEVEL 5 | LEVEL 4 | LEVEL 3 | LEVEL 2 | LEVEL 1 | LEVEL 0

Level 5

.90 x .20 = .18
1.0 x .20 = .20
.90 x .20 = .18
.90 x .20 = .18
.95 x .20 = .19

1.0 x .25 = .25
.85 x .15 = .1275
.75 x .15 = .1125
1.0 x .15 = .15
1.0 x .15 = .15
.95 x .15 = .1425

Level 4

.93 x .60 = .558
.80 x .10 = .08
.9325 x .30 = .27975

.55 x .20 = .11
.60 x .20 = .12
.90 x .20 = .18
.95 x .40 = .38

Level 3

.91775 x .70 = .642425
.79 x .30 = .237

.70 x .40 = .28
.90 x .40 = .36
.85 x .20 = .19

.60 x .30 = .18
.80 x .10 = .08
.40 x .10 = .04
.75 x .20 = .15
0.0 x .30 = 0

.90 x .10 = .09
.80 x .05 = .04
.85 x .00 = .00
1.0 x .05 = .05
.90 x .20 = .18
.95 x .25 = .19
1.0 x .15 = .15
.90 x .10 = .09
.85 x .10 = .085

Level 2

.879425 x .40 = .35177
.83 x .30 = .249
.45 x .20 = .09
.875 x .10 = .0875

Level 1

.77827 x .20 = .155654
.91234 x .30 = .273702
.87910 x .40 = .35164
.80112 x .10 = .080112

Level 0

CPPI
.860478

2

TABLE 5 -- EVALUATION OF PREFERENCE C

	LEVEL 5	LEVEL 4	LEVEL 3
Manageability			
Command			
Chain of Command			.905 x .70 = .6335
Leadership Rating Commanders		.93 x .60 = .558	
Co. A 1/51 Armor	.95 x .20 = .19		
Co. B 1/51 Armor	.95 x .20 = .19		
Co. C 1/51 Armor	.95 x .20 = .19		
Co. C 2/53 Infantry	.85 x .20 = .17		
Battery B 2/23 Artillery	.95 x .20 = .19		
Average Command Years		.80 x .10 = .08	
Leadership Rating Successors		.89 x .30 = .267	
Bn. XO	.95 x .25 = .2375		
Co. A 1/51 Armor	.70 x .15 = .105		
Co. B 1/51 Armor	.80 x .15 = .12		
Co. C 1/51 Armor	.95 x .15 = .1425		
Co. C 2/53 Infantry	.95 x .15 = .1425		
Battery B 2/23 Artillery	.95 x .15 = .1425		
Staff			.83 x .30 = .249
Size		.60 x .20 = .20	
Average Unit Years		.50 x .20 = .10	
Average Staff Years		.85 x .20 = .17	
Confidence Rating		.90 x .40 = .36	
Control			
Span of Control			.70 x .40 = .28
Width of Front			.95 x .40 = .38
SOP Coverage			.90 x .20 = .18
Communication			
Redundant Links Higher			.60 x .30 = .18
FM Frequencies			.80 x .10 = .08
Redundant Links Lower			.40 x .10 = .04
Hard Copy Requirement			.90 x .20 = .18
EW Interference			.50 x .30 = .15
Plan			
Mass			.95 x .10 = .095
Offensive			.95 x .05 = .0475
Surprise			.70 x .00 = .00
Security			.95 x .05 = .0475
Maneuver			1.0 x .20 = .20
Objective			.95 x .25 = .2375
Unity of Command			1.0 x .15 = .15
Simplicity			.80 x .10 = .08
Economy of Force			.85 x .10 = .085
Lethality			
Survivability			
Supportability			

TABLE 5 -- EVALUATION OF PREFERENCE C

LEVEL 5	LEVEL 4	LEVEL 3	LEVEL 2	LEVEL 1	LEVEL 0
				.82525 x .20 = .16505	
			.8825 x .40 = .353		
		.905 x .70 = .6335			
.95 x .20 = .19	.93 x .60 = .558				
.95 x .20 = .19					
.95 x .20 = .19					
.85 x .20 = .17					
.95 x .20 = .19					
	.80 x .10 = .08				
	.89 x .30 = .267				
.95 x .25 = .2375					
.70 x .15 = .105					
.80 x .15 = .12					
.95 x .15 = .1425					
.95 x .15 = .1425					
.95 x .15 = .1425					
		.83 x .30 = .249			
					CPPI .836374
	.60 x .20 = .20				
	.50 x .20 = .10				
	.85 x .20 = .17				
	.90 x .40 = .36				
			.84 x .30 = .252		
		.70 x .40 = .28			
		.95 x .40 = .38			
		.90 x .20 = .18			
			.63 x .20 = .126		
		.60 x .30 = .18			
		.80 x .10 = .08			
		.40 x .10 = .04			
		.90 x .20 = .18			
		.50 x .30 = .15			
			.9425 x .10 = .09425		
		.95 x .10 = .095			
		.95 x .05 = .0475			
		.70 x .00 = .00			
		.95 x .05 = .0475			
		1.0 x .20 = .20			
		.95 x .25 = .2375			
		1.0 x .15 = .15			
		.80 x .10 = .08			
		.85 x .10 = .085			
				.83523 x .30 = .250536	
				.85144 x .40 = .340576	
				.80212 x .10 = .080212	

2

Post Evaluation Analysis. Both evaluation path and sensitivity analysis may be useful to a decision maker attempting to discover why the MAU modeling technique indicated a particular alternative.

Why did A turn out to be the least preferred alternative? From Table 3 and Figures 9-12 it can be seen that manageability received the lowest evaluation of the qualities at level 1 (.76812). In a similar fashion the cause of this low number can be traced through the communication attribute at level 2 (.42) to three sub-attributes of redundant links to higher, redundant links to lower and expected EW interference. Because of the preference structure one would concentrate on improving the redundant links to higher or the expected EW interference. If one more link to higher were available, for example, an improvement of .20 in utility value or .06 in evaluation value would be achieved. Level 2 increases from .42 to .48 which then changes level 1 to .78012 and alternative A to .822089, an improvement of .3%. Unfortunately, not much can be done with the EW interference sub-attribute since the data input is an estimate and the utility curve is fixed.

Of course, the EW interference estimate could be wrong and a "moderate" estimate may be more accurate. From a sensitivity standpoint the utility value could increase to .5 contributing .15 to level 2, .03 to level 1 and .006 to level 0 for an improvement to .825689 or .7%.

Neither this revised estimate of enemy capability nor the improvement in redundant links upsets the alternative choice, but the analysis is useful. In many cases deficiencies which are easy and inexpensive to correct are highlighted.

Summary. Chapter III has presented a detailed high resolution battalion task force model to demonstrate the multiple attribute utility modeling process. The five procedural steps were described and examples were provided to illuminate the advantages of MAU modeling. The mathematical procedure is meticulous and frustrating at times, but provides a powerful evaluation technique which can be analyzed without recalculating every path in the model. This audit trail ability should be extremely valuable to an analyst faced with a complex decision situation. Fortunately, calculations for analysis are easily programmed for computer support, leaving the analyst to focus on the issues rather than the numbers.

CHAPTER IV

MANAGEMENT IMPLICATIONS OF MULTIPLE ATTRIBUTE UTILITY MODELS

Introduction

The thrust of the report to this point has been on the specifics of how multiple attribute utility modeling can be employed in the force analysis arena. This chapter discusses how extended use of the MAU process can provide a conceptual mission analysis model to assist the entire U.S. Army management structure. A brief description of the force planning environment and the problems of Army management is followed by a discussion of the advantages a MAU based model would present.

Force Planning Environment

All armed services and indeed the entire Federal Government are required to define their fiscal needs by Office of Management of the Budget Circular A-109.[1] The circular prescribes a force planning and analysis process called Mission Area Planning which is implemented by Department of Defense Directives 5000.1 and 5000.2.[2,3] These instructions formalize the planning and programming process with emphasis upon mission considerations. Military managers at all levels will be pressed by these requirements.

Management Problems

No longer is management by intuition adequate to lead organizations effectively. As players in the management process proliferate, the rate of change by geopolitical and technological effects increases, and the amount of information required for critical decision making at the right levels becomes greater, the problems of management will become more difficult. More specifically, the following requirements suggest a significant increase in information flow;

1. Communication between organization levels, using higher, lower, lateral and feedback channels, must provide accurate, understandable, and necessary information.

2. Organizational conflict must be controlled, so that strong critical program review is possible without being divisive.

3. Leadership changes occur frequently and management strategies must be adapted accordingly.

4. Innovations in software and hardware systems and changes in threat conditions must be efficiently incorporated into current organizations and plans.

5. Incremental budget change assessments must be readily evaluated in terms of force impacts.

Management and Multiple Attribute Utility Modeling.

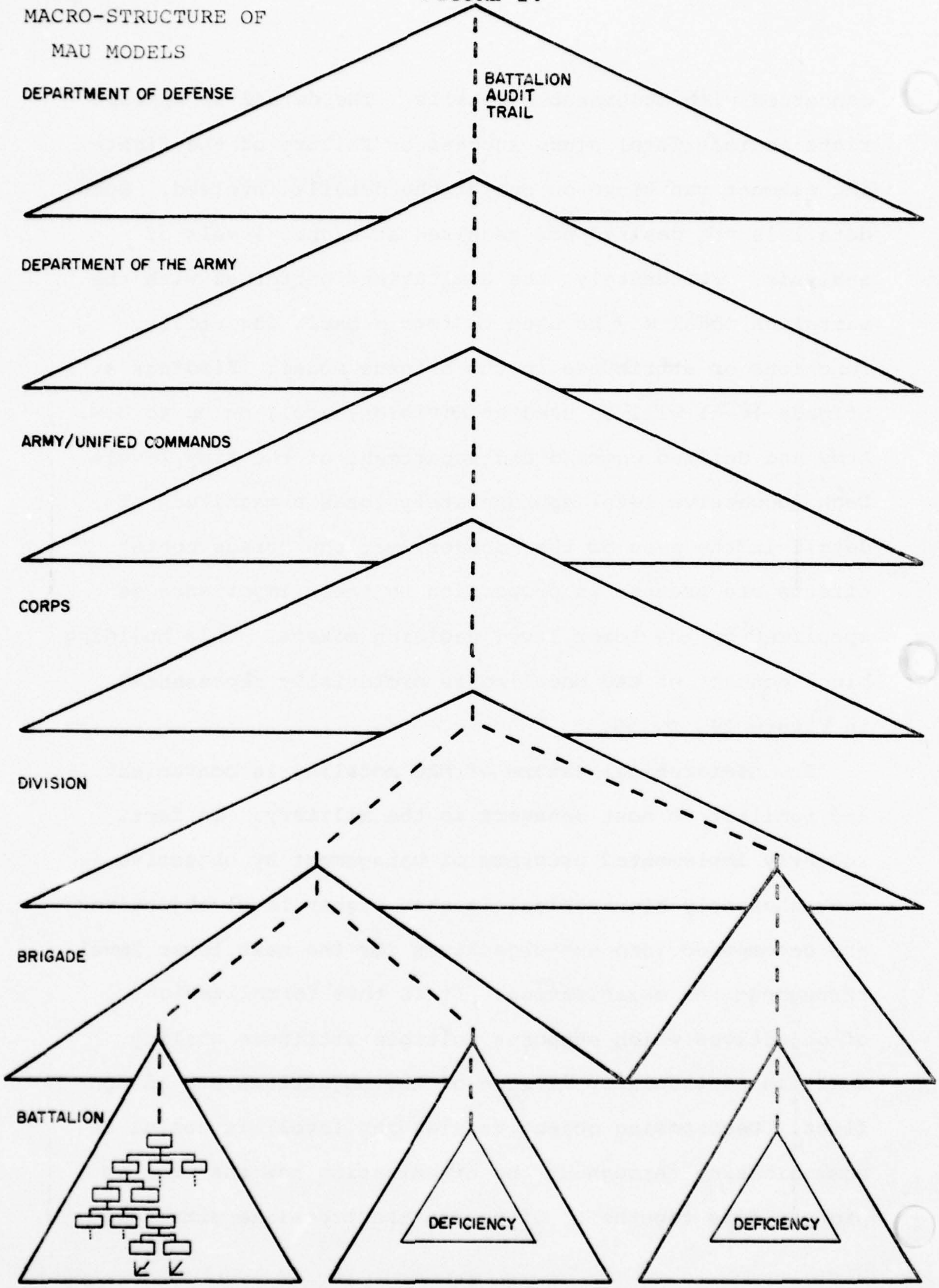
Chapter III discussed how the manager at battalion level can use a MAU model to evaluate employment of alternative force structures. The model used was one of high resolution

concerned with innumerable details. The detail is appropriate at that level since success or failure of the fighting element can hinge on one of the details involved. Such detail is not desired nor required at higher levels of analysis. Fortunately, the evaluations performed with the battalion model may be used to form a basis for utility functions or attributes in the brigade model. Findings at brigade level will be used at division, etc., on up to U.S. Army and Unified Command and Department of the Army levels. Each successive level appropriately loses a magnitude of detail in the eyes of the manager, yet the "grass roots" effects are present in proportion to their importance as specified by the lower level decision makers. This building block concept of MAU modeling is pictorially represented in Figure 14, p. 50.

The hierarchical nature of MAU modeling is convenient and familiar to most managers in the military. In fact, recently implemented programs of management by objective are inherently hierarchical in that higher level objectives are decomposed into sub-objectives for the next lower level, throughout the organization. It is this formalization of objectives which supports multiple attribute utility analysis particularly if some of the objectives are in conflict. Decomposing objectives (at any level) is useful in communicating throughout the organization how the problem picture fits together. Of course the tree-like structure

FIGURE 14

MACRO-STRUCTURE OF MAU MODELS



of objectives and attributes then becomes a "common sheet of music" with which preference values and force characteristics represented by utility functions can be discussed or communicated.

A complete MAU model macrostructure can be used as a tool for advocacy or defense of resource allocation. The commander of a force could make a strong case for specific resources to his commander by demonstrating the improved effectiveness of alternatives employing the requested assets. Of course, the alternatives would be evaluated under the preference structure of the advocating commander. The next higher level commander, with a different preference structure, may be able to defend the status quo. Regardless of the winning position, points of agreement and disagreement are highlighted with the MAU model. At DA and DOD level, the advantages of being able to test alternatives by using a model in Congressional testimony and program planning would prove very beneficial. If a macrostructure based upon multiple attribute utility modeling concepts proves feasible for U.S. Army force analysis, a management information system based upon it will clearly ease the information flow burden.

<u>Advantages of a MAU Management Information System</u>

As stated previously, the paths in a MAU model increase geometrically with the number of levels. Coupled with the number of calculations which must be made to evaluate each alternative, a MAU model is a prime candidate for automation.

The computer software technology needed for MAU models is not particularly complicated and indeed exists in some forms already. Automated utility function and preference structure assessment techniques are available to assist in the modeling process.[4] Conceivably, efficient programs for handling structures, like Figure 14 can be written and made available for use at lower levels. Interactive graphic display devices with access to the macrostructure could be made available to managers at any or all levels. Sensitivity or "what if" analysis could then be effectively performed with this type of hardware and software arrangement.

A management information system (MIS) based on MAU models can provide a convenient format and display (the hierarchy as a matrix), an efficient feedback and evaluation procedure (the computation process) and an effective control mechanism to satisfy the information needs of managers in any detail desired. Once in operation, a MIS would make leadership changes less disruptive by simply using the new decision maker's preference structure to evaluate any new alternatives presented for study. The new decision maker could more readily observe the effects of his ideas versus those of his predecessor through this process eliminating those policy changes which are not productive.

Innovative doctrine, tactics, weapons concepts, etc., could be tested with the MIS. A set of alternatives

employing proposed changes would be generated and then evaluated under the same preference structure and scenario as the baseline alternative set. The results of such a study would quickly illuminate potential improvements to force effectiveness.

In fact, a MAU-based MIS can provide the means for identifying not only force deficiencies in hardware, but also suggestions as to the best candidate for research and development. Each preference structure, if converted to a matrix format like that shown in Table 6, immediately portrays how the decision maker views the integration of resources and plans into a viable force. Each cell in the matrix specifies the contribution of that sub-attribute to the overall objective. Viewed another way, the matrix contains the preferences of a decision maker that could be used to arrange alternatives in priority order. It follows from this prioritizing ability that a MAU-based MIS may assist in the budgeting process.

Zero-Base Budgeting

The Federal Government is now required by executive order to use zero-based budgeting. Essentially, an organization is partitioned into functions and analyzed annually. Decision packages are formed which include all the functions of a particular agency. Finally, these decision packages are arranged in priority order and funded to some level of affordability.

TABLE 6

MATRIX FORMAT OF ATTRIBUTE CONTRIBUTION

ATTRIBUTE	CONTRIBUTION TO LEVEL 4	3	2	1	0
MANAGEABILITY	-	-	-	-	.20
Command	-	-	-	.40	.08
Chain of Command	-	-	.70	.28	.056
Leadership Rating	-	.60	.42	.168	.0336
A	.20	.12	.084	.0336	.00672
B	.20	.12	.084	.0336	.00672
C	.20	.12	.084	.0336	.00672
C	.20	.12	.084	.0336	.00672
B	.20	.12	.084	.0336	.00672
Average Command	-	.10	.07	.028	.00656
Leadership Rating Successes	-	.30	.21	.084	.0168
Bn	.25	.075	.0525	.021	.0042
A	.15	.045	.0315	.0126	.00252
B	.15	.045	.0315	.0126	.00252
C	.15	.045	.0315	.0126	.00252
C	.15	.045	.0315	.0126	.00252
B	.15	.045	.0315	.0126	.0025
Staff	-	-	.30	.12	.024
Size	-	.20	.06	.024	.0048
Average Unit Yrs	-	.20	.06	.024	.0048
Average Staff Yrs	-	.20	.06	.024	.0048
Confidence	-	.40	.12	.048	.0096
Control	-	-	-	.30	.06
Span of Control	-	-	.4	.12	.024
Width of Front	-	-	.4	.12	.024
SOP Coverage	-	-	.2	.06	.012
Communication	-	-	-	.20	.04
Redundant Links Higher	-	-	.30	.06	.012
FM Frequencies	-	-	.10	.02	.004
Redundant Links Lower	-	-	.10	.02	.004
Hard Copy	-	-	.20	.04	.008
FW Interference	-	-	.30	.06	.012
Plan	-	-	-	.10	.005
Mass	-	-	.05	.005	.001
Offensive	-	-	.10	.01	.002
Surprise	-	-	.00	.00	.00
Security	-	-	.05	.005	.001
Maneuver	-	-	.20	.02	.004
Objective	-	-	.25	.025	.005
Unity of Command	-	-	.15	.015	.003
Simplicity	-	-	.10	.01	.002
Economy of Force	-	-	.10	.01	.002

A MAU based management information system would assist managers in preparing not only the decision packages, but also in ranking them. For a high level, low resolution model, a decision package is simply a way to accomplish a stated objective. To develop the best way to meet the objective, alternative decision packages could be evaluated with the MAU process. Management benefits, since MAU modeling requires concentration on analysis and decision maker preferences rather than on numbers. Through the alternative evaluation technique, a rank ordering is achieved which can assist the manager in his efforts to prioritize for the budgeting process.

MAU techniques may be most appropriate for task analysis within mission areas. The process begins with a zero base, adds up all the advantages and benefits, highlighting deficiencies, and provides a quantitative priority list. With this a marginal analysis of budget increments or decrements can be performed.

Summary

Management strategies have become more and more complex due to the increased sophistication of the decision environment. Information needs have mushroomed as advanced techniques of data manipulation have become available. Multiple attribute utility modeling promises to assist the manager at all levels in his decision making tasks. Additionally,

it is able to provide the framework for an effective management information system which would be useful in the planning, programming, and budgeting process.

CHAPTER V

CONCLUSIONS

Multiple Attribute Utility Modeling Methodology

The following conclusions can be drawn about the general MAU modeling methodology.

1. Multiple attribute utility modeling is a sophisticated and powerful technique, yet straightforward and simple in application. The hierarchical schematic used in the process is familiar to most decision makers and analysts, making it easy to follow when presented.

2. The mathematical manipulations required are not difficult and consist essentially of operations analogous to expected value calculations of decision analysis. The computational ease makes MAU modeling amenable to computer programming.

3. The derivation of utility functions and preference values are critical and must be done thoughtfully. The concepts of independence, both mathematical and preferential, can be employed to assist in the development of utility functions and to keep the mathematics simple.

4. The hierarchical nature of the model provides a convenient communication device because each level decomposes and defines the higher level objective or concept precisely and comprehensively. Analysts and decision

makers can use the model structure to advantage in discussing problems highlighted by the MAU process.

5. The hierarchical structure and the calculation procedure provide an "audit trail" allowing the analyst to trace the results of a study as necessary and to document the contribution of a particular alternative being evaluated. Deficiencies in an alternative are highlighted and can be studied for sensitivity through the use of the "audit trail."

6. The multiple attribute utility modeling process is not a true optimal strategy technique, since it employs the use of more than one objective. The procedure indicates the alternative which is the best (indicated by an index) trade-off choice among several objectives as viewed by a specific decision maker.

Force Analysis

The multiple attribute utility modeling process applied to force analysis problems yields the following conclusions:

1. Multiple attribute utility modeling is an appealing technique for use in analyzing alternative force designs to address varying threat conditions. Traditional procedures are limited in handling the conflicting objectives involved in making force analysis decisions. MAU modeling allows multiple objectives to be considered at any level from Department of the Army to platoon.

2. Hierarchical objective structures have potential for providing universal force analysis models capable of being used to analyze new weapons systems, tactical concepts, and threat conditions. It is not necessary to recreate the hierarchy at each level each time needed, rather considerable savings can be realized by good documentation and model reuse.

3. MAU modeling allows force alternative comparisons to be made for any prescribed situation. The process is consistent, exhaustive, and systematic. Creation of alternatives is limited only by the imagination and skill of the analyst.

4. Care must be taken when formulating force analysis models to assess the issues of mathematical and preferential independence and to use modeling to take advantage of the simplifications that can be obtained.

5. In the force analysis application, the use of MAU modeling automatically gives an indication of priority (rank order) of the alternative force designs being studied. The quantitative indicator used for ranking, called a combat power potential index for purposes of this study, is adequate only to indicate relative worth. The prioritizing ability has potential use in mission area analysis for the Army planning, programming, and budgeting process.

Implications for Management

There are several conclusions which can be made concerning the management implications of force analysis with MAU modeling.

1. The flexibility of MAU modeling permits an entire hierarchy of force analysis models to be aggregated from the very lowest level up or decomposed from top down. The macrostructure developed would be useful to management to evaluate alternatives for any organizational level. A series of models would be necessary because the number of paths to be assessed proliferates geometrically as the number of levels of the hierarchy increases.

2. The systematic evaluation procedure requires the decision maker to study his preference attitudes about conflicting qualities or concepts. The process of establishing and justifying one's value judgments is certainly difficult but illuminates and quantifies intuitive feelings.

3. A macrostructure of force analysis models and a proper preference structure can form the basis for a management information system. Current software and hardware computer packages are sophisticated enough to handle MAU modeling. Force planners would find a MAU based management information system a significant aid in prioritizing development programs and studying the potential impact of new weapons, organization, and doctrinal concepts.

4. Finally, the advantages of multiple attribute utility modeling for decision making argue for a wider use of the technique particularly for military applications. The procedures of utility function formation, preference structure assessment and objective and attribute decomposition should be made part of the curriculum at academic institutions teaching the science and art of decision making.

NOTES

CHAPTER II

1. Decision Process Subcourse, Management Trimester, College of Naval Command and Staff, Naval War College, Newport, RI, 1977-1978.

2. Ward Edwards and Marcia Guttenberg, "Experiments and Evaluations: A Reexamination," Carl Bennet and Arthur Lumsdaine, eds., Evaluation and Experiment (New York: Academic Press, Inc., 1975), pp. 428-430.

3. H.M. Ellis and R.L. Keeney, "A Rational Approach for Government Decisions Concerning Air Pollution," A.W. Drake, R.L. Kenney and P.M. Morse, eds., Analysis of Public Systems (Cambridge, Mass: MIT Press, 1972), p. 87.

4. Ralph Keeney and Howard Raiffa, Decisions with Multiple Objectives (New York: John Wiley & Sons, 1976), pp. 101-116.

5. Ibid., p. 208.

6. For a more vigorous treatment of preference determination the text referenced in Note 4 is recommended.

CHAPTER III

1. U.S. Army, Operations, Field Manual 100-5, Washington: 1 July 1976.

2. Direct preference ratings are made by the decision maker after he establishes the preference structure (Step 4). These ratings must be made independently from any preference values established for the path in the hierarchy. For example, the simplicity of an alternative plan must be rated independently of how much the principle of war "simplicity" contributes to combat power potential through manageability.

CHAPTER IV

1. Office of Management and Budget, Mission Budgeting, OMB Circular A-109 (Washington: 5 April 1976).

2. U.S. Department of Defense, Major System Acquisition, DOD Circular 5000.1 (Washington: 18 January 1977).

3. U.S. Department of Defense, Major System Acquisition Process, DOD Circular 5000.2 (Washington: 18 January 1977).

4. Ralph L. Keeney and Howard Raiffa, Decisions with Multiple Objectives (New York: John Wiley & Sons, 1976), p. 349.

BIBLIOGRAPHY

Barclay, Scott, et al. Handbook for Decision Analysis. McLean, Virginia: Decisions and Designs, Inc., September 1977.

Barclay, Scott and Peterson, Cameron. Multi-Attribute Utility Models for Negotiations. Technical Report 76-1. McLean, Virginia: Decisions and Designs, Inc., March 1976.

The BDM Corporation. Analysis of V Corps Planning Methodology for Covering Force. Vienna, Virginia: March 1977.

Brown, Fred R., ed. Management: Concepts and Practice. Washington, DC: Industrial College of the Armed Forces, 1967.

Brown, Rex V., et al. Decision Analysis for the Manager. New York: Holt, Rinehart and Winston, 1974.

Brown, Rex V., et al. An Analysis of Alternative Mideastern Oil Agreements. Technical Report DT/TR 75-6. McLean, Virgina: Decisions and Designs, Inc., December 1975.

Carter, Jimmy. "Jimmy Carter Tells Why He Will Use Zero-Base Budgeting." Nations Business, January 1977.

Dianich, David F. "Integrated Multi-Attribute Utility Modeling and Management Information Systems." A contributed paper to the 39th Annual Military Operations Research Symposium, Annapolis, Maryland, June 1977.

Easton, Allan. Decision Making: A Short Course for Professionals. New York: John Wiley & Sons, 1976.

Edwards, Ward and Guttentay, Marcia. "Experiments and Evaluations: A Reexamination." Carl Bennet and Arthur Lumsdaine, eds. Evaluation and Experiment. New York: Academic Press, Inc., 1975.

Ellis, H.M. and Keeney, R.L. "A Rational Approach for Government Decisions Concerning Air Pollution." A. W. Drake, R. L. Kenney, and P.M. Morse, eds. Analysis of Public Systems. Cambridge, Massachusetts: M.I.T. Press, 1972.

Farquhar, P.H. "Pyramid and Semicube Decomposition of Multi-Attribute Utility Functions." Operations Research, V. 24, March 1976.

__________. "Fractional Hypercube Decomposition Theorem for Multi-Attribute Utility Functions." Operations Research, V. 23, September 1975.

Fishburn, Peter C. Utility Theory for Decision Making. New York: John Wiley & Sons, Inc., 1970.

Hayes, Richard E. Measurement of Combat Effectiveness in Marine Corps Infantry Battalions. Arlington, Virginia: CACI, Inc-Federal, October 1977.

Hayward, Philip. "The Measurement of Combat Effectiveness." Operations Research, V. 16, 1968.

Keeney, Ralph L. and Raiffa, Howard. Decisions with Multiple Objectives: Preferences and Value Tradeoffs. New York: John Wiley & Sons, Inc., 1976.

Mitchell, William and Dianich, David F. "A Structure for Analyzing and Planning by Mission Area: Tactical Air Command's Mission Area Analysis (MAA) Approach." A contributed paper for the 1978 Air University Airpower Symposium, Air War College, Maxwell AFB, Alabama, February 1978.

Newman, Robert J. Differential Weighting in Multi-Attribute Utility Measurements: When it Should Not and When it Does Make a Difference. Technical Report SSRI 76-6. Los Angeles, California: Social Science Research Institute, USC, August 1976.

O'Connor, Michael F. Procedures for Assessing the Value of Command and Control Capabilities. Technical Report 77-4. McLean, Virginia: Decisions and Designs, Inc., 1977.

Pyhrr, Peter A. "Zero-Base Budgeting." Harvard Business Review, November-December 1977.

Ryan, Terrance C. Evaluation System for Proposed Theatre of Construction Structures. V. I-IV, Technical Report. Construction Engineering Research Laboratory Project #4A764717D895. Champaign, Illinois, June 1973.

U.S. Army War College. Army Command and Management: Theory and Practice. Carlisle Barracks, Pennsylvania, 1977.

U.S. Department of the Army. Field Manuel 30-40, Handbook on Soviet Ground Forces. Washington, DC: U.S. Department of the Army, 30 June 1975.

__________. Field Manual 100-5, Operations. Washington, DC: U.S. Department of the Army, 1 July 1976.

__________. Field Manual 101-5, Command and Control of Combat Operations. Washington, DC: U.S. Department of the Army, 1 July 1977. (Final Approved Draft.)

U.S. Naval War College. Defense Economics and Decision Making Course. Decision Process Subcourse. Newport, Rhode Island, 1977-78.

APPENDIX I

MATHEMATICAL BACKGROUND

APPENDIX I

MATHEMATICAL BACKGROUND

Introduction

The purpose of this appendix is to present a concise notation and the mathematical foundation for multiple attribute utility modeling. The general problem, hierarchical model, utility function use, preference value use and alternative evaluation procedure are discussed. A very complete and rigorous development of multiple attribute utility theory, including theorem derivations and excellent bibliography is contained in the text of Decisions with Multiple Objectives: Preferences and Value Tradeoffs by Keeney and Raiffa.[1]

General Decision Problem

Mathematically, the decision maker must select an optimal alternative $\underline{Z}^*$ from among:

$$\underline{Z}_1 = (C_{11}, C_{21}, C_{31} \ldots C_{ij} \ldots C_{1n})$$

$$\underline{Z}_2 = (C_{21}, C_{22}, C_{23} \ldots C_{ih} \ldots C_{2n})$$

$$\vdots$$

$$\underline{Z}_i = (C_{i1}, C_{i2}, C_{i3} \ldots C_{ij} \ldots C_{in})$$

$$\vdots$$

$$\underline{Z}_m = (C_{m1}, C_{m2}, C_{m3} \ldots C_{mj} \ldots C_{in})$$

where:

> $\underline{Z}^* \equiv$ the best alternative force structure of m alternatives based upon some criteria.
>
> $\underline{Z}_i \equiv$ an alternative force structure resulting in a set of consequences or payoffs C_{ij}

The problem is how does one define and measure the consequences of each alternative and how can the definitions and measurements be aggregated to determine the best alternative based upon a set of objectives.

Hierarchical Model. A hierarchy of objectives and attributes is used to decompose the decision problem into layers. Each layer is a more detailed subdivision of the next higher level. The intent is to present the decision maker with a logical, easily described breakdown of the problem into component parts. The hierarchy model used meets the same criteria as a decision tree, that is, single root, non-looping branching, etc. Further, the use of utility functions, preference values and the evaluation procedure are analogous to payoffs, probability branching and the "folding back" techniques used in decision analysis.

Utility Functions. At the end of each hierarchy path or tree tip a consequence C_{ij} can be found for the alternative studied. Unfortunately, alternative consequences are incommensurable and must be converted into a useful measure. Utility functions are developed which map the worth of the consequence C_{ij} into a utility value U_{ij}. The subscript

i indexes the alternatives from 1 to m, and subscript j indexes the consequences and resulting utility values from 1 to n.

Some typical utility function forms are shown in Figure I-1. They are depicted in an unbounded space, although utility values are commonly confined to a specified range such as $0.0 \leq U_{ij} \leq 1.0$. In the descriptions which follow, the term "marginal utility" means the change in utility for the next increment of consequence quantity.

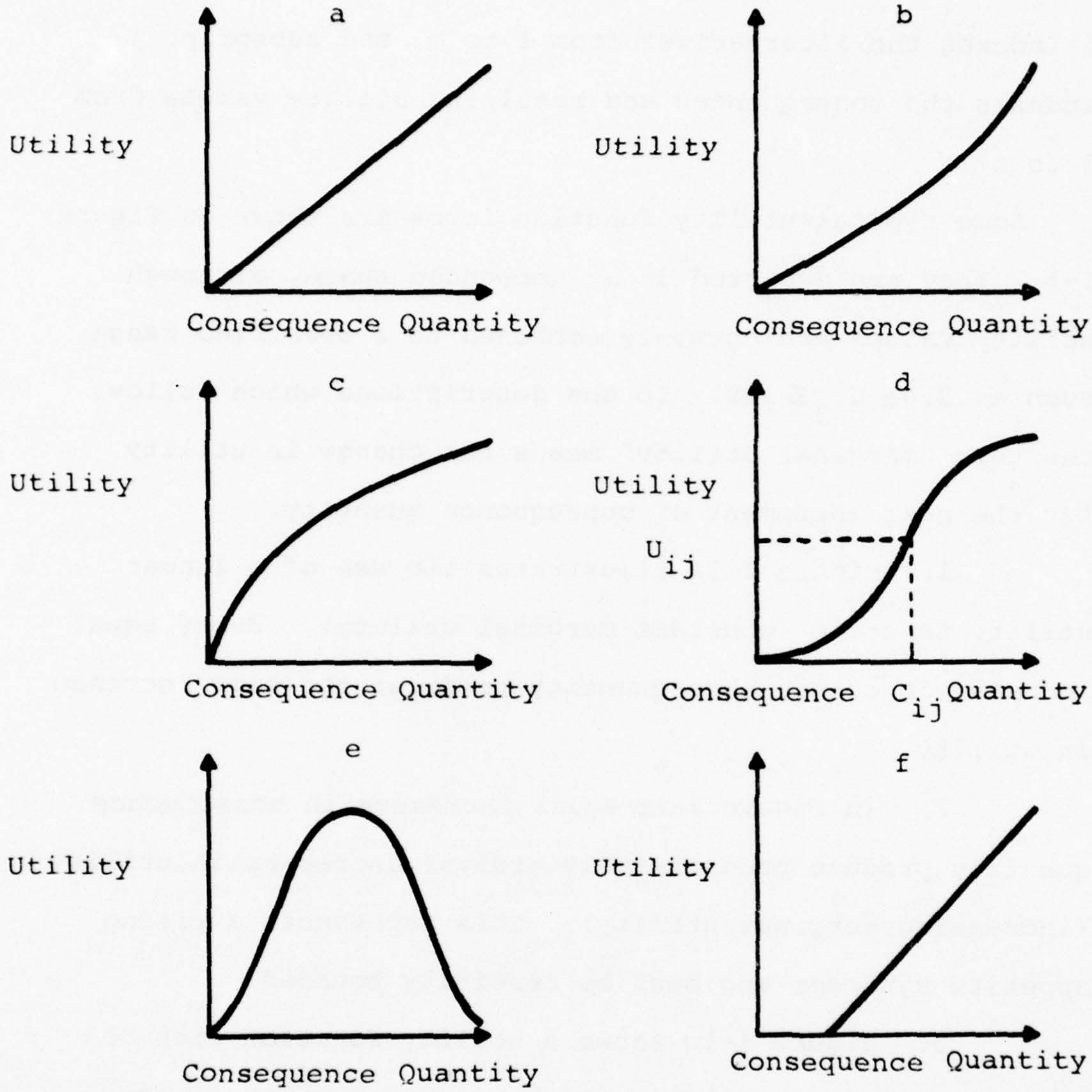
1. Figure I-1a illustrates the use of a linear utility function (constant marginal utility). Every equal increase in consequence quantity produces the same increase in utility.

2. In Figure I-1b equal increases in consequence quantity produce progressively greater increases in utility (increasing marginal utility). This represents a rising appetite syndrome and must be carefully bounded.

3. Figure 1-1c shows a utility function with decreasing marginal utility. Each equal increment of consequence quantity yields a smaller utility increase than the last.

4. The "S" shape of Figure 1-1d illustrates the common condition of increasing then decreasing marginal utility. For example, appetite rises with the first increments of consequence quantity or calorie intake, but then abates after a certain level is reached.

FIGURE I-1
SAMPLE UTILITY FUNCTIONS



a. Linear utility function; constant marginal utility
b. Non-linear utility function; increasing marginal utility
c. Non-linear utility function; decreasing marginal utility
d. S-shaped utility function; increasing marginal utility to point C_{ij}; decreasing marginal utility beyond point C_{ij}
e. U-shaped utility function
f. Discontinuous utility function

5. In Figure I-le the first portion is much like Figure 1-1c but in this case there is a threshold beyond which increasing consequence quantity yields decreasing utility. This "inverted U" shape is not uncommon especially in such cases as workers overcrowding a production facility.

6. Figure 1-1f represents one of many possible discontinuous utility functions. Here, no utility is realized until a minimum amount of consequence quantity is available. A common discontinuity arises if there is an integer quantity requirement, i.e., the utility of 1/2 a person. Some stair-step discontinuous utility functions are used in Chapter III.

Preference Values

All nodes are, for MAU modeling, considered chance events. As such the evaluation procedure uses preference values which measure the importance of the sub-attributes in an expected value fashion. It turns out that the preference structure sought meets the definition of a probability measure at each tree node.

$$0.0 \leq X_{lk} \leq 1.0$$

$$\sum_{l=1}^{p} X_{lk} = 1.0$$

where:

$X_{lk} \equiv$ a dimensionless preference value between 0.0 and 1.0

$l \equiv$ an index indicating the element being considered at a specific node

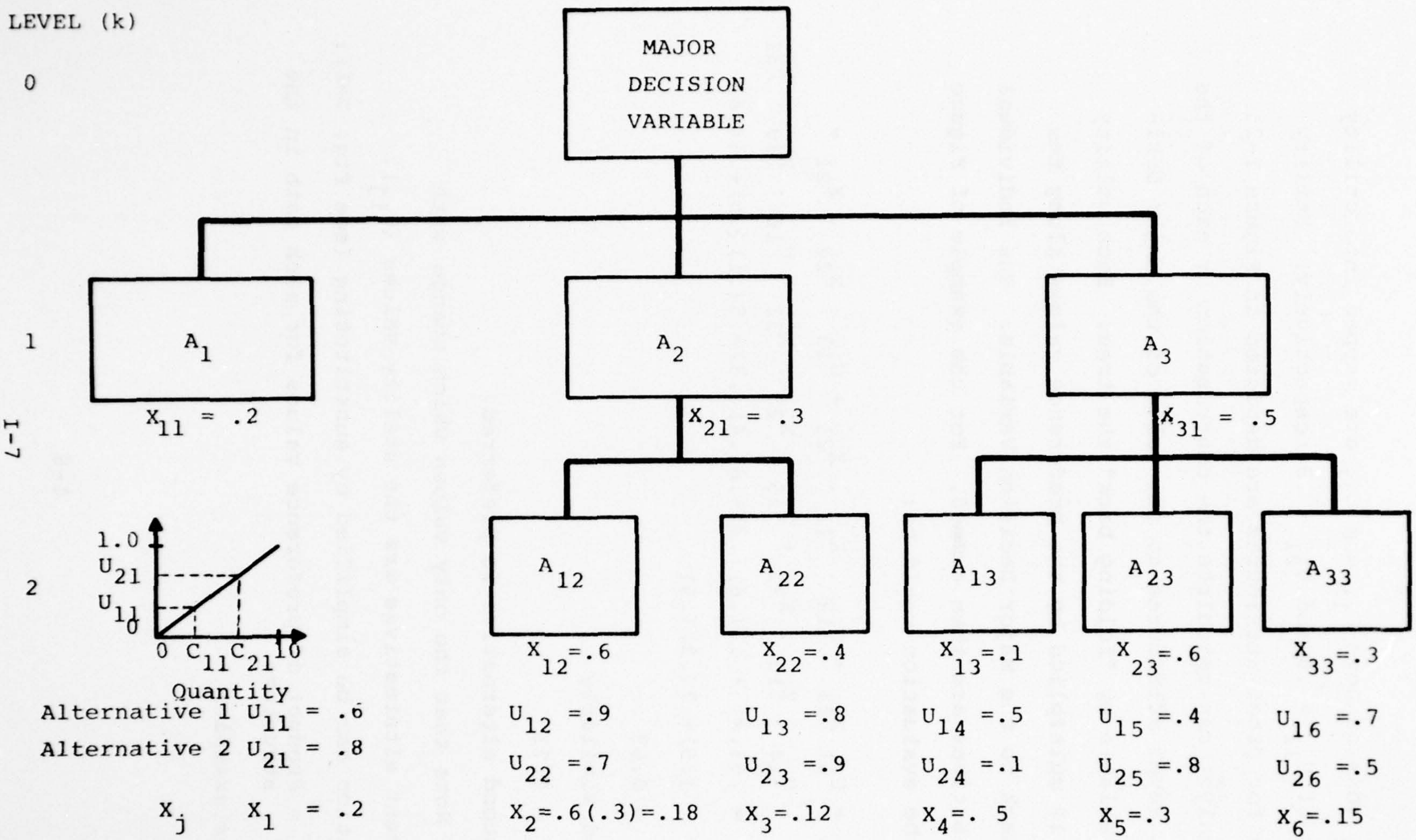
$k \equiv$ an index indicating a particular hierarchical level.

There has been some discussion and research which suggests that in many situations equally valid decisions may be made by ignoring the preference value problem and giving all sub-attributes an equal weight.[3] This approach is not advocated in this report as the authors feel much valuable information about the decision maker's value structure would be lost and the analytical power of MAU modeling diminished.

Alternative Evaluation Procedure

The calculation procedures is analogous to the "folding back" process used in decision tree analysis. Figure I-2 is an example of a simple hierarchical structure. In this case the Major Decision Variable was first decomposed into three attributes (A_1, A_2, A_3). A_1 required no further decomposition wheras A_2 and A_3 were divided into sub-attributes A_{21} and A_{22} and sub-attributes A_{31}, A_{32}, A_{33} respectively. Preference values are assumed to have been obtained as shown on the figure (note that $X_1 + X_2 + X_3 = 1.0$, $X_{21} + X_{22} = 1.0$ etc.). At the lowest level of each branch utility functions (U) are derived. A sample utility function is shown for attribute A_1 only. Assume that there are two alternatives to consider. The analyst determines the specific utility value (U_{ij}) for each of the lowest level consequences (C_{ij}).

FIGURE I-2
HYPOTHETICAL MAU HIERARCHY



For A_1 consequences C_{11} and C_{21} are mapped into utility values of $U_{11} = .6$ and $U_{21} = .8$ respectively. Utility values for other attributes are depicted in Figure I-2. The analyst can calculate the contribution of each of the lowest level attributes to the value of the Major Decision Variable by "folding back" the tree. Each utility value is multiplied by the preference values along the path back to the Major Decision Variable. The individual contributions are then summed. For the example of Figure I-2, the evaluation would be:

$$E_1 = U_{11}\, X_{11} + U_{12} \cdot X_{12} \cdot X_{21} + U_{13} \cdot X_{22} \cdot X_{21} + U_{14} \cdot X_{13} \cdot X_{31} + U_{15} \cdot X_{23} \cdot X_{31} + U_{16} \cdot X_{33} \cdot X_{31} \tag{1}$$

$$= .6(.2) + .9(.6)(.3)+.8(.4)(.3)+.5(.1)(.5)+.4(.6)(.5)+.7(.3)(.5)$$

$$= 0.63$$

and similarly

$$E_2 = 0.71$$

The second alternative is preferred.

Note that the only values which change with different alternatives are the utility values (U_{ij}). Evaluation can be simplified by substituting (see Fig. I-2):

X_j = Product of preference values for each path in the structure

For example:

$$X_1 = X_{11}$$

$$X_2 = X_{12} \cdot X_{21}$$

$$X_3 = X_{22} \cdot X_{21}$$

$$\vdots$$

$$X_6 = X_{33} \cdot X_{31}$$

into equation (1)

A simplified general equation can then be written:

$$E_i = \sum_{j=1}^{n} X_j \cdot U_{ij} \tag{3}$$

where "n" is the number of paths or consequences in the structure.

It should be noted that this additive structure relies upon the existence of mutual preferential independence (see Chapter II) in the MAU hierarchy.

NOTES

1. Ralph Keeney and Howard Raiffa, Decisions with Multiple Objectives: Preferences and Value Tradeoffs (New York: John Wiley and Sons, 1976).

2. Allan Easton, Decision Making: A Short Course for Professionals (New York: John Wiley and Sons, 1976), V. 5, pp. 12-14.

3. J. Robert Newman, Differential Weighting in Multi-Attribute Utility Analysis (Los Angeles: Social Science Research Institute, 1976).

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Alternative Force Evaluation with Multiple Attribute Utility Modeling.		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) RYAN, Terrance C., MAJ, USA Thomas, Charles S., MAJ, USA		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Center for Advanced Research Naval War College Newport, Rhode Island 02840		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Center for Advanced Research Naval War College Newport, Rhode Island 02840		12. REPORT DATE April 1978
		13. NUMBER OF PAGES 86
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

GROUND LEVEL AND WARFARE; WEAPON SYSTEM; ARMY (UNITED STATES); TACTICAL WARFARE; QUANTITATIVE ANALYSIS; METHODOLOGY; MANAGEMENT; LETHALITY; SURVIVAL (GENERAL); TASK FORCE; MATHEMATICAL ANALYSIS; MILITARY BUDGETS; FORCE LEVEL AND MILITARY FORCES (UNITED STATES); PLANNING

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Multiple Attribute Utility (MAU) Modeling is described in detail. A five step paradigm of the process is developed and a user's manual is presented which enables the reader to apply MAU modeling to virtually any problem characterized by competing objectives. The MAU modeling technique is found to be sophisticated yet straightforward in application. The framework of a model comparing alternate force organizations at the Army Battalion Task Force level is created to illustrate the power of the technique. The MAU approach seems ideally suited for dealing with the complex tradeoffs involved in force planning at all levels. Conclusions

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are drawn about the MAU modeling methodology, its application to force alternative evaluations at all levels, and its implications for managers of complex systems.